TEMPERATURE OF REGENERATOR-SUPERHEATED WATER IN A WATER-COOLED REACTOR AT AN ATOMIC POWER STATION

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At the present time the atomic power station which has been investigated most is the type in which a heterogeneous reactor is used with pressurized water as a coolant. However, the economic aspects of the operation of these stations still requires clarification. Especially important is the problem of determining the best temperature for the water superheater in the secondary circuit when a regenerative cycle is used.

The contradictory results obtained in [1-5] are explained by the difference in the criteria used in evaluating the economic characteristics of atomic power stations.

We consider the relation between the temperature of the regenerative water superheater in the secondary circuit (feed-water) \( t_{\text{feed water}} \) and the other parameters.

In a coal-powered electric station the economy of utilization is determined by the efficiency factors for the electric power station \( \eta_{\text{stat}} \):

\[
\eta_{\text{stat}} = \eta_{\text{boil}} \eta_{\text{therm}} \eta_{\text{turb}}
\]

where \( \eta_{\text{boil}} \) is the efficiency of the boiler system, \( \eta_{\text{therm}} \) is the thermal efficiency, and \( \eta_{\text{turb}} \) is the electrical efficiency of the turbogenerator.

At an atomic power station we have

\[
\eta_{\text{stat}} = \eta_{\text{r}} \eta_{\text{sg}} \eta_{\text{therm}} \eta_{\text{turb}}
\]

where \( \eta_{\text{r}} \) is the efficiency of the reactor and \( \eta_{\text{sg}} \) is the efficiency of the steam generator.

Assuming that the heat losses in the reactor and the steam generator are comparatively small, we can write

\[
\eta_{\text{stat}} = \eta_{\text{therm}} \eta_{\text{turb}}
\]  \hspace{1cm} (1)

If the steam parameters are the same, the lowest feasible value of \( \eta_{\text{turb}} \) at an atomic power station is the same as that for a coal-powered station.

The factor \( \eta_{\text{therm}} \), however, behaves differently. In present-day coal-powered electric power stations, the boiler systems of which are, as a rule, provided with air superheaters, the best value of \( \eta_{\text{therm}} \) for given steam parameters is determined by the regenerative cycle of the turbine system. The economy of operation of such boiler systems is essentially independent of the factor \( \eta_{\text{therm}} \).

At an atomic power station, however, the economy of operation does depend on the factor \( \eta_{\text{therm}} \). The electric power of an atomic power station \( N \) is given by the product \( Q_{r} \eta_{\text{therm}} \) (if \( \eta_{\text{turb}} \) remains fixed) where \( Q_{r} \) is the amount of heat generated in the reactor (kcal/hr). The quantity \( Q_{r} \) depends on the temperature of the water \( t_{f} \) admitted to the reactor and consequently, on the temperature of the feed-water \( t_{\text{feed water}} \) and is effected by the factor \( \eta_{\text{therm}} \) since the latter quantity is a function of \( t_{\text{feed water}} \). In contrast with a coal-powered station, the maximum electrical power for an atomic station \( N_{\text{max}} \) is not obtained at the maximum value of \( \eta_{\text{therm}} \) and, consequently, not at optimum values of \( t_{\text{feed water}} \) as determined by the condition for achieving maximum \( \eta_{\text{therm}} \).

The effect of \( t_{\text{feed water}} \) on the economy of operation of atomic powered stations can be compared with the effects of \( t_{\text{feed water}} \) on the economy of operation of coal-powered stations when the boilers do not have air superheaters.
We consider the quantities which determine the values of $Q_\text{r}$ and $\eta_{\text{therm}}$ and the relations between these quantities and the feed-water temperature $t_{\text{feed water}}$.

**Quantities which affect $Q_\text{r}$.** The transfer of heat from the surface of the cladding of the fuel element to the coolant is described by the well-known equation

$$Q_\text{r} = F \alpha \Delta t.$$

In the present case it is assumed that all the heat generated in the fuel elements is transferred to the water. A small amount of heat, which is also evolved in the moderator (in a graphite moderator this quantity is 7-8% [6]), is taken into account by appropriate factors.

The surface of the fuel-element cladding $F$ is taken as the starting point in the present calculations. The heat transfer $\alpha$ from the surface of the fuel-element to the water, at fixed water velocity in the reactor channels, depends only on the physical parameters of the water $\lambda$, $P_r$, and $\nu$, which in turn depend on temperature:

$$a = f\left(\frac{K_\lambda P_r^{a_s}}{\nu^{a_s}}\right).$$

The temperature differential $\Delta t$ — the mean temperature difference between the cladding surface and the water — depends on the maximum temperature of the fuel-element $t_0$ and on the water temperature at inlet and exit to the reactor channels, $t_1$ and $t_2$, respectively.

To determine $\Delta t$ the value of $t_0$ is averaged over the height and radius of the reactor:

$$t_0 = \frac{\int_0^{\pi} \int_0^L r f(t, r) \, dr \, dl}{\int_0^{\pi} \int_0^L r f(t, r) \, dr \, dl},$$

where $\delta t$ is the temperature differential at the cold end of the steam generator.

The choice of $t_1$ depends on $\Delta t$. The quantity $t_2$ is given and, because of reliability considerations, is usually taken as 30-35°C below the boiling temperature corresponding to the water pressure at exit from the reactor. The change in water temperature over the height of the fuel-element can be considered linear.

Solving simultaneously the equations for heat conduction and heat transfer, we obtain an expression for $\Delta t$:

$$\Delta t = \frac{-t_0 - \frac{t_2 - t_1 + t_2}{2}}{1 + a \left(\frac{B_1}{2\lambda_1} - \frac{1}{\lambda_3}\right)}.$$