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HEAT POLLUTION GENERATED BY THERMAL POWER STATIONS

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Abstract. *Temperature of cooling water in combined-system power stations. Share of river water that can be used for cooling in a combined system with natural-draft cooling towers, depending on load, river water temperature and weather conditions. Variation of the river water share for different specific load levels of the cooling tower. Classified graph of the cooling time for natural draft cooling towers operating in combined systems. Hourly variation of cooling water temperature for constant-power operation. Combined system cooling schemes.*

Rezumat. *Temperatura apei de răcire la centralele electrice în circuit mixt. Cota de debit folosibilă din apa unui râu la răcirea în circuit mixt, cu turnuri de răcire cu tiraj natural funcţie de încărcare, de temperatura apei din râu şi condiţiile atmosferice. Variaţia cotei de debit folosibil pentru diferite încărcări specifice ale turnului de răcire. Curba clasată a intervalului de răcire la turnuri cu tiraj natural funcţionând în circuit mixt. Variaţia orară a temperaturii apei de răcire pentru funcţionarea la putere constantă. Scheme de răcire în circuit mixt.*

Keywords: power stations, cooling time, water temperature, cooling tower, combined system

1. Introduction

The need to improve fuel efficiency in thermal power stations is subject to various technical, economic and environmental constraints. A change by one degree in the temperature of cold water means an increase by 7-9.5 degrees in the superheated steam cycle and by 2-2.6 degrees in the saturated steam cycle. For the cooling of power plants, the restrictions concerning the heating of surface waters result in a higher temperature of the cold source. This is because heat has to be either partly or completely evacuated in the environment, through cooling towers, and the temperature of the water cooled in a closed circuit is in any case higher that the natural temperature of river water. Figure 1 shows the variations in the average monthly temperature of the water cooled in towers and of surface water in the climate conditions of the Danube Plain. The impact of temperature differences justifies, from an economic viewpoint, the use of a combined cooling system, considering the economic circumstances and the flow pattern of Romanian rivers, even though rivers provide cooling water for thermal power stations for only 25% of the total time.

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As a result, approx. 75%, of the total power installed in condensation units in Romania use combined cooling systems, unlike in other counties with an advanced energy industry, where either open-system cooling, supported by major rivers, or closed-system cooling have been used so far.

2. Limitation of heat pollution and energy saving

The maximum share of river water in combined-system cooling Z_{max} depends on the maximum river water temperature increase $T_{o\ max}$ - T_o, on the heating of water in the turbine condenser ΔT_c, on the weight of cooling towers in the total cooling, as well as on the quality of the cooling towers and on the climate conditions, that is, on the temperature of the water cooled by towers while operating in a combined system, T_{w2}.

$$Z_{\max} = \frac{T_{0\max} - T_0}{\dfrac{x-\alpha}{1-\alpha}\left(T_{0\max} - T_0\right) + 1 - \dfrac{x\alpha}{1-\alpha}\left(T_c + \alpha T_{w2} - \alpha T_0\right)}.$$

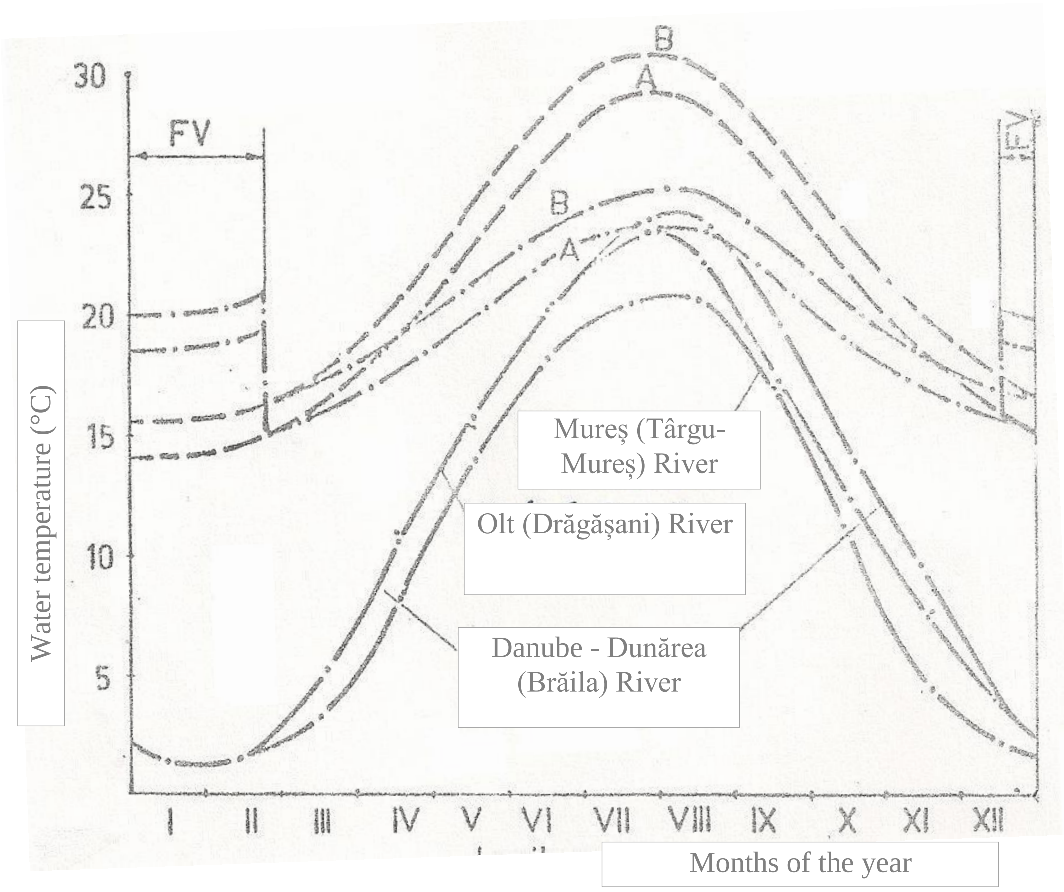

Fig. 1. Temperature of cooling water in thermal power stations.

x - *percentage of water loss in the cooling tower;*

____ - *water from surface sources (rivers);*

_ _ _ - *water cooled in natural-draft cooling towers;*

_._._ - *water cooled in forced draft cooling towers;*

A - *normal-load tower;*

B - *overloaded tower;*

FV - *operating time of forced draft towers with the fan turned off.*

The critical point defines the required capacity of cooling towers. This critical point occurs in August, when river flow rates are low, while temperatures are high.

Where natural draft towers are used, we have the following situation for various specific tower load levels and different degrees of condenser water heating (1):

- Z is minimal for a share of towers α = **0.80 – 0.85** (*figure 2*);
- the tower cooling quality, i.e. the hydraulic load r, sensibly affects the cooling rate *(figure 3).*

The increase in the hydraulic load, as a result of the economic conditions, reduces the acceptable percentage of river water used, raises the specific fuel consumption and expands heat pollution.

The particular operating conditions of a cooling tower in a combined system, that is, the operation for limited periods, especially in the summer, and a tower cooling time below the condenser heating time, favor the use of forced draft towers in situations of this type [2].

The cooling time for a natural draft tower operating in a combined-system cooling scheme for a unit assumed to constantly work at full capacity with a condenser cooling level **ΔT_c = 10 degrees** has the classified values shown in *Figure 4*.

The condenser cooling time T_c varies in reverse proportion to the flow rate Z. Previous research indicated that **ΔT_c = 8 degrees** is optimal for open-system cooling, but this value for combined systems is **9 to 10 degrees**, as the input of towers rises.

For closed-system heating in plants operating in a basic regime, this value is equal to or slightly above **10 degrees.**

In plants that use the condensation section for a reduced number of hours, that is, in plants designed to operate in peak or semi-basic regime, as well as in the final condensation sections of district heating plants, the optimal nominal heating level in condenser is **12 to 13 degrees.**

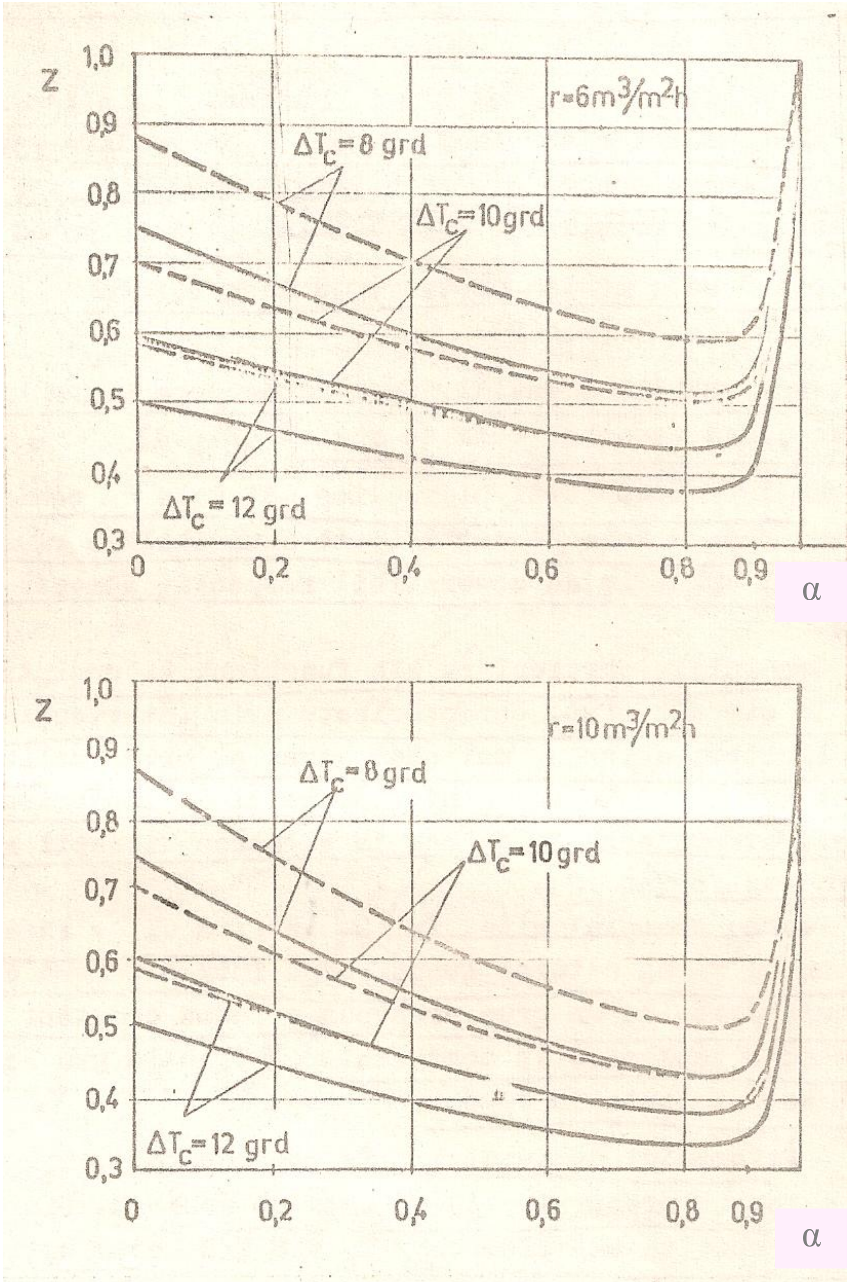

Fig. 2. Share of river water usable in a combined cooling system with natural draft towers for a load r is stated in m^3 / m^2 h, river water temperature $T_0 = 26°C$ and climate conditions $T_a = 28°C$; $\varphi_a = 0.6$ ($\sigma_a = 22°C$).

______ - $T_{o\,max} = 32$ °C

_ _ _ - $T_{o\,max} = 33$ °C

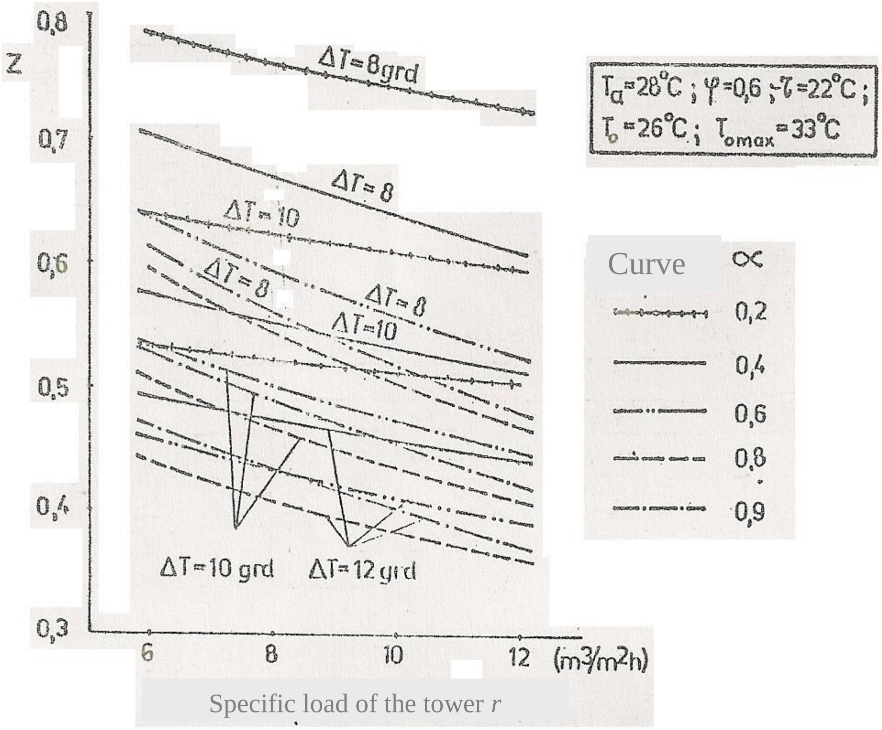

Fig. 3. Variation of the river water share Z for different specific load levels r of the cooling tower.

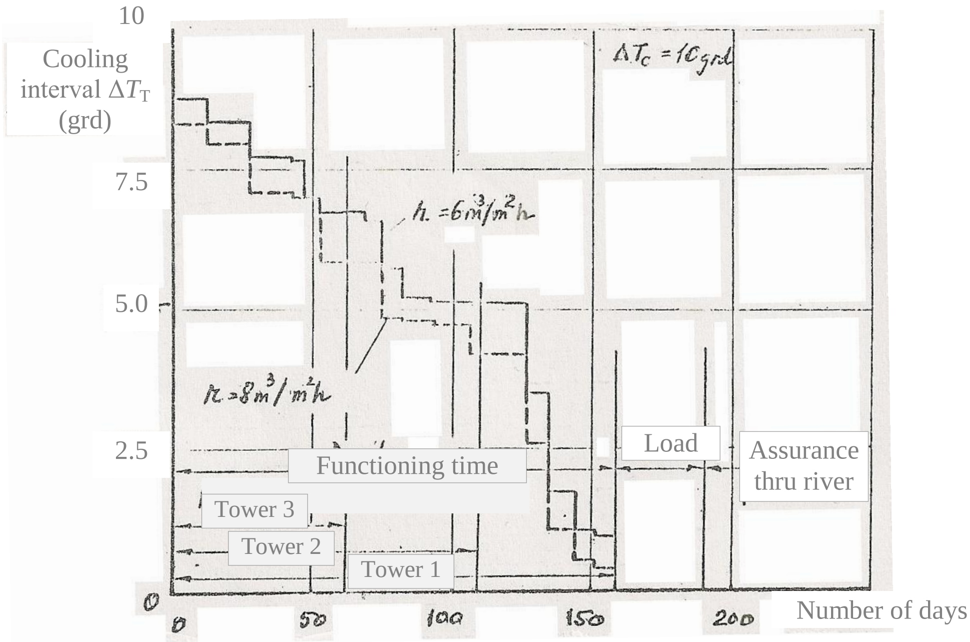

Fig. 4. Classified graph of the cooling time for natural draft cooling towers operating in a combined system 2.

This optimal efficiency condition takes into account the combined impact of variation in the specific fuel consumption depending on the condensation temperature and of variation in the additional pumping power required to raise the water to towers.

However, it opposes the aim to limit the temperature of the water returned to the river.

The value of Z changes by **40%** for an increase of ΔTc from **8 to 12 degrees.**

Variations in the natural temperature of river water over a day are rather limited and, under stable weather conditions, do not exceed **1 to 1.5 degrees** in Romania.

The change of water temperature in a combined or closed circuit system depends on the major air temperature variations occurring during the day.

Figure 5 shows a diagram illustrating this variation considering the average hourly conditions prevailing in July and August in the Danube Plain.

If a buffer volume of water is introduced in the loop of a closed or combined cooling system, the cooling water temperature sinusoid is attenuated according to the (B) curves in *Figure 5*, even if such volume is assumed to have no heat exchange with the air.

The computer solving of the system of equations that model the operation (including a differential equation) showed that the attenuation of temperature variation does not have a sensible impact on the average specific daily fuel consumption, either in constant-load operation or in case of operation at reduced load during the night [3].

The presence of the buffer water volume results in a peak temperature lower by **approx. 1.5 degrees** in closed cooling systems and by **approx. 1 degree** in combined cooling systems, contributing to the limitation of heat pollution.

The solution is particularly interesting in plants with variable operating regime, where the attenuating effect is even more significant.

By raising the operating temperature during the night, this solution also has some side effects:

- the additional discharge of heat into the air by the open surface of the heated water volume;
- the heat exchange in cooling towers at night, favoring the convective exchange due to the temperature difference between water and air. This, in its turn, limits to some extent the loss of water as a consequence of evaporation.

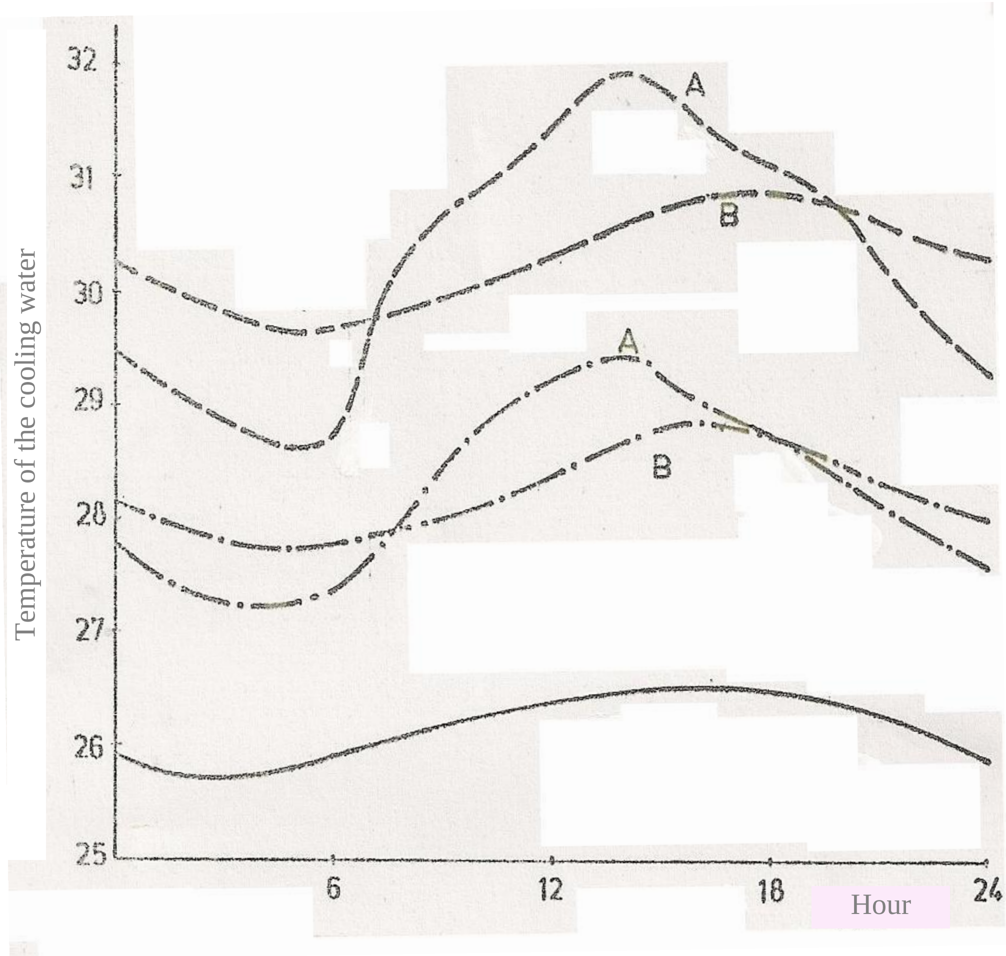

Fig. 5. Hourly variation of cooling water temperature for constant-power operation.

_____ - *open system cooling (natural river temperature T_o);*

_ _ _ - *closed system cooling;*

_._._ - *combined system cooling with a rate of participation of cooling towers* $\alpha = 0.6$.

A - *system without thermal inertia;*

B - *system with thermal inertia (corresponding to an accumulation volume equivalent to* 20 h).

In order to increase the usable share of surface water, while achieving a minimal condensation temperature and limiting the temperature of the returned water, serial cooling can be applied to the entire volume of water used in the cooling process.

Cooling towers or cooling ponds are both practicable solutions.

3. Conclusion

The combined-system cooling schemes with and without accumulation of water are presented comparatively in *Figure 6* and *Figure 7*.

DIAGRAMS WITHOUT ACCUMULATION

DERIVATION TOWERS SERIES TOWERS

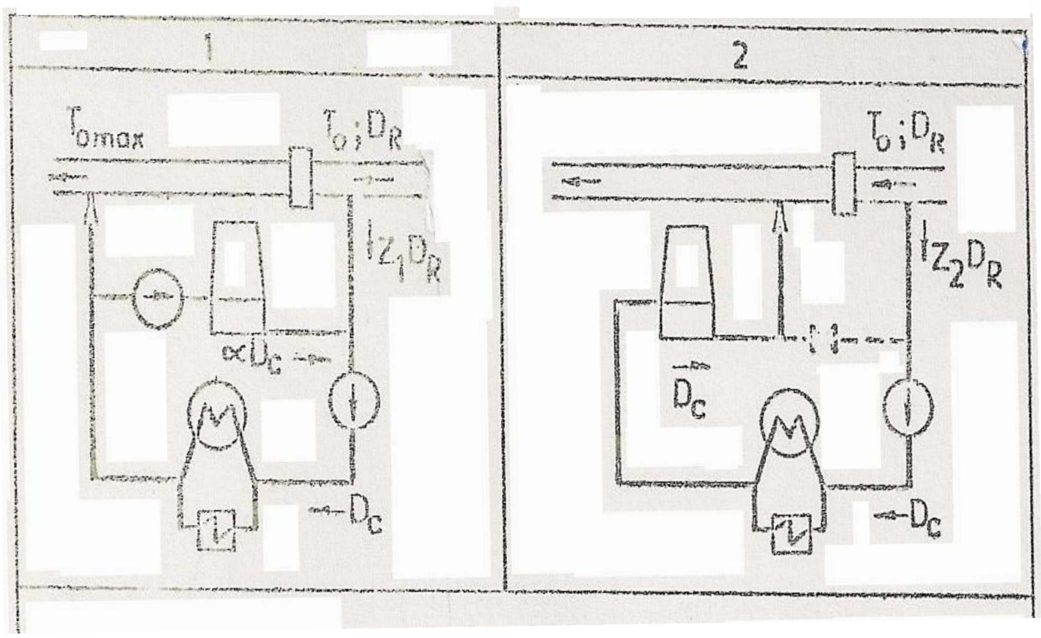

Fig. 6. Combined system cooling schemes for diagrams without accumulation.

The combined cooling system 1 is better than the serial cooling system 2 in point of limiting pollution and it also saves pumping power, as water is pumped to the towers only when river water is used.

The use of a volume of water collected downstream from the point of return, with diffuse discharge of the water in the formed pond has, in any case, a positive impact in point of limiting heat pollution and leads to the following preliminary conclusions concerning this cooling scheme:

- the amplitude of the daytime variation in the river water temperature downstream from the plant is limited and the maximum temperature is reduced. Therefore, if constant downstream temperature conditions are accepted, the share *Z* of river water is expanded by increasing the downstream water volume;

- if the plant completely stops, the downstream water temperature decrease rate is slowed down, thus limiting, in both spring and summer, the negative impact on the river fauna and preventing a possible environmental hazard;
- the discharging of water from the pond into the river causes water aeration.

DIAGRAMS WITH ACCUMULATION

UPSTREAM DOWNSTREAM

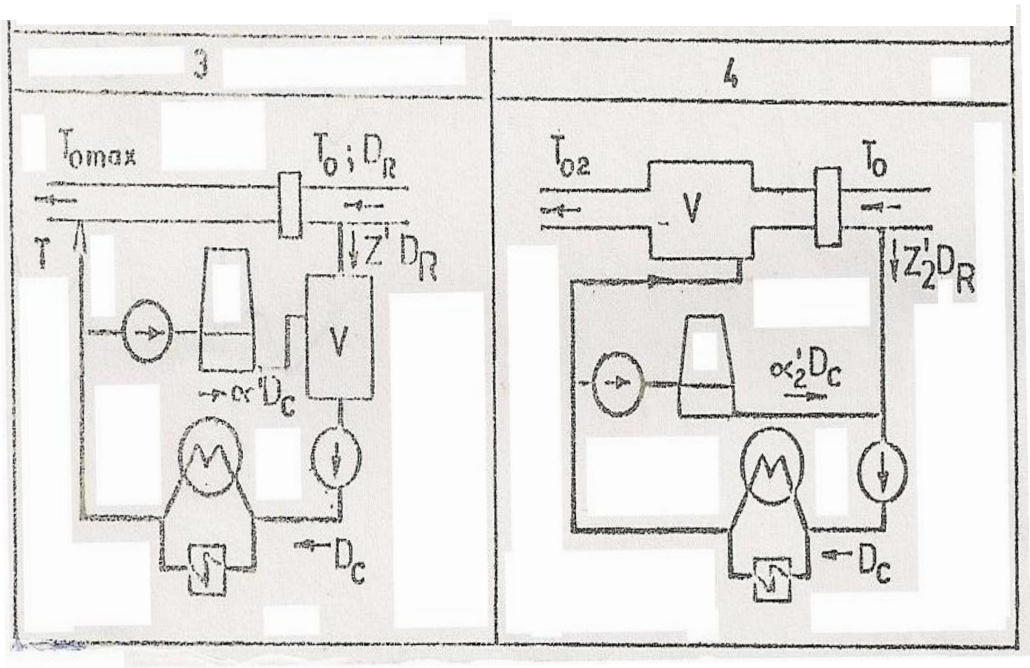

Fig. 7. Combined system cooling schemes for accumulation diagrams

The presence of a cooling pond permits the installation of hydraulic turbines in order to harness the existing head.

They have a higher power than the recovery turbines placed on plant's tailrace, as they use the entire flow, not only the Z share.

A recovery hydropower plant of this type can be activated at any time as an emergency source to supply power to the vital internal services of the thermal power station.

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