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## THE COMBINED METHOD OF MAKE-UP WATER TREATMENT FOR COOLING AND HEATING PURPOSES

The paper describes a new coordinated method of the make-up water purification for cooling and heating. Raw water being treated with mineral acids to reduce its alkalinity is then pumped into the spray distribution system of a cooling tower. Afterwards, some of the cooling water, after preheating in condensers and deaeration, is poured into the heating system. The treatment of water produces no wastewater. The results of a 3-year operation of large industrial plant have been given. Compulsory requirements for the water quality in the heating system have been discussed.

The Łódź 2 Power Station has an open, recirculating cooling system with water flow rate of 27,000 m<sup>3</sup>/h and a foredesigned temperature difference of 12°C. The designed water losses in the system during the maximum power production periods are calculated to be over 400 m<sup>3</sup>/h. In practice, however, due to the upward trend in the amount of heat production at the cost of power generation with steam condensation in condensers, the maximum losses of water in summer amount to about 200 m<sup>3</sup>/h.

The power station provides heat for the central, southern, and western quarters of the Łódź city in a total amount of 511 Gcal/h. The high-temperature heating system comprises tens of kilometers of hot-water pipelines, up to 700 mm in diameter, spread all over the area of 7,450 m<sup>2</sup> around the power station. Water circulates in the heating system at a constant flow rate of 6,400 m<sup>3</sup>/h. It is heated in the power station up to 75–150°C, depending on the ambient temperature. To this end six membrane heat exchangers with bleed steam from turbines and/or steam reduction station are used or two oil-fired boilers which operate in periods of hard frost. Heat is supplied to the consumers through the secondary local hot-water and central heating systems which include 1,435 membrane heat exchangers for the household hot-water and 805 central heating cycles connected directly to the primary heating system by hydroelevators. Water losses in the primary heating system normally amount to 120–130 m<sup>3</sup>/h and increase further during operational disturbances — sometimes more than twice as much.

The make-up water for both the cycles was prepared by catalytic cold-lime process in high-efficiency reactors (Gyractor-type) followed by filtration in pressure filters: the

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gas in make-up water for the heating system was additionally stripped applying thermal method.

For almost 20 years the cooling system has operated successfully. Some troubles, however, have been encountered in the operation of the heating system: some whitish loose deposit was observed to circulate with the water and settle in the lowest parts of the system, thus clogging the sludgers and electromagnetic valves for the automatic control of the sectors of the heating system. In the areas located far from the power station, hard deposits were precipitated on inner pipeline walls and heat-exchange surfaces, decreasing the heating water flow rate and thereby deteriorating the heat transfer to consumers. There were also troubles with the oil-fired water boilers in the power station which due to formation of boiler scale (up to 3 mm thick) on the heat-exchange surfaces had to be cleaned chemically and thus withdrawn from the operation in the winter heating periods.

The main causes of the deposits precipitation in the heating system are the following: 1. penetration of raw water, containing a considerable amount of bicarbonates, into the heating system due to leaking, 2. improper quality of the make-up water.

The cold-lime process was not completed in the Gryactor reactors and the rapid filters but proceeded also beyond the water treatment plant where loose deposits of magnesium hydroxide were precipitated. The treated water contained, moreover, some amount of calcium hydroxide, showing an increased methyl orange alkalinity. Bicarbonates, present in the heating water in concentration exceeding admissible standards, were decomposed by heat and calcium hydroxide and transformed into calcium carbonate and magnesium hydroxide. The quality of the make-up water is characterized by parameters given in tabs. 1 and 2.

Taking into account the unsatisfactory quality of the water treated by cold-lime process, as well as limited capacity of the water treatment plant and its toilsome operation, a new method of the make-up water treatment for the cooling and heating systems has been presented including thermal and chemical conjunction of both the systems. The procedure comprises reduction of the make-up water alkalinity for both cycles by treating with sulphuric and hydrochloric acids, pumping the treated water into the spray distribution system of the cooling tower, and the uptake of some amounts of cooling water heated up in condensers to compensate for the losses in the heating system.

The equipment for the water treatment includes two storage tanks for sulphuric acid each 40 m<sup>3</sup> in volume, two plunger metering pumps of the NDA 16 RS type of a unit capacity of 38.5 dm<sup>3</sup>/h, and connecting pipings. Hydrochloric acid is gravitationally proportioned from the regeneration solution tanks in the water demineralization plant. In addition, there is a pipeline which connects the manifold pipe of cooling water after condensers with the deaerating heater for the make-up water. The installation diagram is shown in figure.

For a normal operation of the heating system it is essential that water has no corrosive qualities and no scale-forming tendencies. Among the salts present in raw water, calcium carbonate has the lowest solubility, thus being precipitated during the thermal decom-

Table 1

Average make-up water composition for heating system in 1976  
Średni skład wody uzupełniającej w układzie grzejnym w 1976 r.

Month	Phenolphthalein alkalinity meq/dm <sup>3</sup>	Total alkalinity meq/dm <sup>3</sup>	Total hardness meq/dm <sup>3</sup>	pH	Thermal stability index*
I	0.36	0.97	1.07	9.0	1.36
II	0.61	1.24	1.21	9.4	1.23
III	0.68	1.30	1.50	9.4	1.41
IV	1.22	1.88	1.86	9.8	1.25
V	0.37	1.21	0.93	9.1	1.15
VI	0.69	1.29	1.00	9.4	1.29
VII	0.24	0.86	0.64	8.8	1.45
VIII	0.43	1.02	0.86	9.1	1.26
IX	0.47	1.18	1.18	9.2	1.27
X	0.42	1.30	1.11	9.1	1.32
XI	0.57	1.16	1.04	9.2	1.23
XII	1.25	1.77	1.79	9.5	1.16
Average	0.61	1.26	1.18	9.3	1.28

\* Water is stable when its thermal stability index is equal to 1.00.

Table 2

Average composition of the heating-system water in 1976  
Średni skład wody w układzie grzejnym w 1976 r.

Month	Phenolphthalein alkalinity meq/dm <sup>3</sup>	Total alkalinity meq/dm <sup>3</sup>	Total hardness meq/dm <sup>3</sup>	pH	Thermal stability index*
I	0.14	0.80	0.95	8.1	1.17
II	0.16	0.67	0.82	8.5	1.10
III	0.18	0.82	0.99	8.4	1.24
IV	0.25	0.69	0.67	8.5	1.08
V	0.26	0.95	0.95	8.5	1.13
VI	0.56	1.20	1.06	9.1	1.23
VII	0.09	1.13	1.52	8.3	1.33
VIII	0.11	0.81	1.32	8.3	1.19
IX	0.17	0.84	0.94	8.2	1.12
X	0.21	0.79	0.82	8.3	1.15
XI	0.32	0.72	0.82	8.6	1.21
XII	0.19	0.75	0.79	8.2	0.90
Average	0.22	0.85	0.97	8.4	1.15

\* Water is stable when the thermal stability index is equal to 1.00.

position of bicarbonate and releasing corrosive carbon dioxide. Therefore, according to the state regulations, the carbonate hardness of the heating water is limited to  $0.7 \text{ meq/dm}^3$  [2] at most. Sodium bicarbonate is also thermally decomposed releasing carbon dioxide, thus the soft water of a high alkalinity is not acceptable for heating systems because of its corrosive properties. Hence, it is advisable to limit rather the total alkalinity of the heating water than its carbonate hardness, then considering an allowable value of  $0.7 \text{ meq/dm}^3$ .

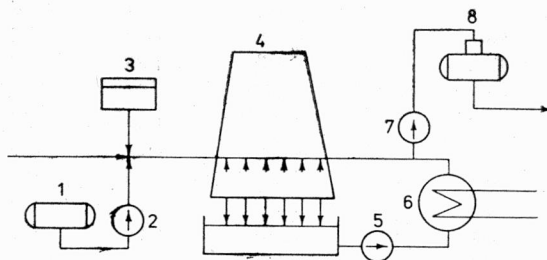


Fig. Flow lay-out of make-up water treatment plant

1 -  $\text{H}_2\text{SO}_4$  tank; 2, 5, 7 - pumps; 3 -  $\text{HCl}$  tank; 4 - cooling tower; 6 - condenser; 8 - gas stripping heater

Rys. Schemat przepływu wody uzupełniającej w zakładzie oczyszczania

1 - zbiornik  $\text{H}_2\text{SO}_4$ ; 2, 5, 7 - pompy; 3 - zbiornik  $\text{HCl}$ ; 4 - chłodnia kominowa; 6 - kondensator; 8 - ogrzewacz odpowietrzający

According to the method proposed the make-up water alkalinity is reduced to the value that can be maintained at the required level in the heating water, taking into account the raw leaking water entering the heating system within the local heat exchangers. The operational practice has shown that the standard value of methyl orange alkalinity of the heating water, i.e.  $0.7 \text{ meq/dm}^3$ , does not ensure a normal work of the oil-fired water boilers, particularly those of PTWM 180 type. In these boilers water is heated up to the temperature of  $150^\circ\text{C}$  on the average at high heat capacity periods, however, in particular parts of the boilers local temperatures are considerably higher, involving even water evaporation. That is why in order to ensure permanent and failureless operation of these boilers the admissible maximum value of total alkalinity of water has to be reduced to  $0.5 \text{ meq/dm}^3$ .

Among the other salts present in the water, calcium sulphate which is characterized by a low solubility product may precipitate under these conditions, even if the total alkalinity of water is maintained at the required level. The solubility product of calcium sulphate is shown in tab. 3 [1].

The power station of the city of Łódź takes raw water from various sources (ground water from deep wells and water from municipal distributing system). Chemical composition of the waters and their volumetric ratios are different. The basic amounts of raw water are supplied by deep wells, the city main water from which the amount of water taken in the winter seasons reaches 40% of the total consumption being an additional

Table 3

Solubility product of calcium sulphate  
Iloczyn rozpuszczalności siarczanu wapnia

Solubility product	Temperature, °C				
	90	100	120	150	160
$K_{CaSO_4}$	$11.3 \times 10^{-6}$	$7.6 \times 10^{-6}$	$3.7 \times 10^{-6}$	$1.4 \times 10^{-6}$	$0.93 \times 10^{-6}$

source. When the percentage of city water is higher, the raw water mixture is characterized by higher concentrations of chlorides and sulphates and lower total alkalinity. That is why to reduce its alkalinity smaller amounts of mineral acids are required.

The average raw water quality at the power station during the heating periods is as follows:

$$\begin{aligned} Ca^{++} &= 3.0-3.2 \text{ meq/dm}^3, & HCO_3^- &= 3.0-3.7 \text{ meq/dm}^3, \\ Mg^{++} &= 0.3-0.4 \text{ meq/dm}^3, & SO_4^{--} &= 0.3-0.2 \text{ meq/dm}^3, \\ Na^+ &= 0.4-0.6 \text{ meq/dm}^3, & Cl^- &= 0.4-0.3 \text{ meq/dm}^3. \end{aligned}$$

Based on the solubility product of calcium sulphate, the admissible sulphate concentration in the heating water was calculated for the maximum water temperature (150°C) and for the highest hardness and total alkalinity stated in the raw water:

$$K_{CaSO_4} = f_{II}^2 [Ca^{++}] [SO_4^{--}], \quad (1)$$

where:

$K_{CaSO_4}$  — the solubility product of calcium sulphate,

$[Ca^{++}]$ ,  $[SO_4^{--}]$  — molar concentrations of ions in water,

$f_{II}$  — the activity coefficient of bivalent ions dependent on ionic strength of the solution, its value being equal to

$$\log f_{II} = -0.5 z_i^2 \frac{\sqrt{J}}{1 + \sqrt{J}}, \quad (2)$$

where:

$z_i$  — electrovalence,

$J$  — the ionic strength of the solution which may be calculated from the formula:

$$J = \frac{1}{2} \sum_i c_i z_i^2, \quad (3)$$

where:

$c_i$  — molar ion concentration.

For the given water, the activity coefficient of bivalent ions  $f_{II} = 0.7163$ , hence molar concentration of sulphates at 150°C is equal to:

$$[\text{SO}_4^{--}] = \frac{1.4 \times 10^{-6}}{1.6 \times 10^{-3} \times 0.7163^2} = 1.7052 \times 10^{-3} \text{ M/dm}^3 = 3.41 \text{ meq/dm}^3.$$

Considering that water in the oil-fired boilers may be locally overheated to a temperature over 150°C, the allowable concentration of sulphates in the heating water was accepted to be 2.0 meq/dm<sup>3</sup>. To this end the alkalinity of raw water within the range of allowable sulphates concentration was reduced with sulphuric acid, and to required value — with hydrochloric acid.

Table 4

Average make-up water composition for heating system in January, 1979  
Średni skład wody uzupełniającej w układzie grzejnym w styczniu 1979 r.

Day	Total alkalinity	Total hardness meq/dm <sup>3</sup>	SO <sub>4</sub> <sup>--</sup> meq/dm <sup>3</sup>	Cl <sup>-</sup> meq/dm <sup>3</sup>	pH	Thermal stability index*
2	0.38	3.80	0.95	3.07	7.7	0.98
3	0.33	3.60	1.07	2.73		
4	0.32	3.68	1.30	2.54	7.7	
5	0.37	3.52	1.44	2.56	7.6	1.04
6	0.38	4.08	1.36	2.62		
8	0.20	3.76	1.62	2.90		0.94
9	0.33	3.72	1.33	2.82		
10	0.49	4.00	1.19	2.48	7.9	
11	0.38	3.60	1.54	2.62	7.8	
12	0.47	3.72	1.48	2.62	7.8	
15	0.34	4.04	1.22	2.62		
16	0.55	3.32	1.51	2.45		
17	0.52	3.48	1.18	2.47	7.7	
18	0.57	3.72	1.16	2.34	7.8	
19	0.50	3.72	1.50	2.32	7.8	
20	0.41	3.08	1.43	2.21	8.3	0.95
23	0.49	3.28	1.55	2.17	8.2	
24	0.48	3.44	1.45	2.31	7.8	
25	0.43	3.40	1.15	2.39	7.8	0.95
26	0.43	3.64	1.46	2.54		
27	0.43	3.48	1.31	2.45	8.0	
29	0.48	3.36	1.45	2.31	8.1	
30	0.41	3.24		2.42	8.0	
31	0.45	3.20	0.88	2.54	8.0	
Average	0.42	3.57	1.32	2.52	7.9	0.97

\* Water is stable when its thermal stability index is equal to 1.00.

Table 5

Average heating water composition in January, 1979

Średni skład nagrzewanej wody w styczniu 1979 r.

Day	Total alkalinity meq/dm <sup>3</sup>	Total hardness meq/dm <sup>3</sup>	SO <sub>4</sub> <sup>--</sup> meq/dm <sup>3</sup>	Cl <sup>-</sup> meq/dm <sup>3</sup>	pH	Thermal stability index*
2	0.52	3.92	2.02	2.68	7.7	0.98
3	0.54	4.12	1.27	2.73		
4	0.52	3.84	1.19	2.70	7.6	
5	0.48	3.80	1.13	2.59	7.5	1.08
6	0.48	4.00	1.18	2.62		
8	0.48	3.56	1.29	2.61	7.7	0.97
9	0.61	3.88	1.15	2.68		
10	0.58	3.56	1.48	2.68	8.1	
11	0.48	3.60	1.63	2.82	8.1	
12	0.53	3.63	1.56	2.59	8.1	
15	0.53	4.04	1.31	2.59		
16	0.51	3.72	1.15	2.61		
17	0.50	3.72	1.16	2.54	7.9	
18	0.54	3.96	0.98	2.45	8.0	
19	0.57	3.60	1.54	2.42	8.1	
20	0.34	3.24	1.23	2.45	8.4	1.03
23	0.53	3.48	1.29	2.37	8.1	
24	0.50	3.52	1.19	2.37	8.0	
25	0.53	3.48	1.36	2.34	7.8	1.01
26	0.50	3.60	1.16	2.34		
27	0.53	3.52	1.12	2.42	8.2	
29	0.48	3.56	1.36	2.42	8.2	
30	0.53	3.36		2.37	8.2	
31	0.51	3.20	0.98	2.42	8.1	
Average	0.51	3.67	1.29	2.53	8.0	1.03

\* Water is stable when its thermal stability index is equal to 1.00.

In summer, the oil-fired water boilers are idle and the heating water is heated to the temperature of 75°C, that is why higher total alkalinity of water (up to 0.7 meq/dm<sup>3</sup>) and the sulphate concentrations are admitted due to much higher solubility of calcium sulphate at this temperature.

An important step of the make-up water treatment for the heating system is a complete physical and chemical stabilization of the water in the cooling system after treatment with mineral acids. The cooling water and the make-up water for the heating system have an optimum pH value and no scale-forming tendencies.

The method discussed has been successfully used for three years. The results are partly shown in tabs. 4 and 5. After peak heating periods 1978/79 and 1979/80, the inner sur-

faces of furnace water-wall tubes and convection section tubes of the oil-fired boilers have been checked and no traces of scales found.

This new chemical-thermal joint method of make-up water treatment for cooling and heating systems has brought several technical and economical advantages, the main being:

1. improvement of efficiency and durability of the heating system,
2. improvement in heating economy (re-use of the heat from condensers),
3. decrease of raw water consumption for washing filters by about 500,000 m<sup>3</sup> annually resulting from excluding rapid filters from operation,
4. wasteless make-up water treatment decreased considerably the amount of wastewater discharged by the water treatment plant to the municipal sewage system and, consequently, reduced significantly the capital cost of a new wastewater treatment plant,
5. construction of new plant for make-up water treatment for the heating system of a capacity of 340 m<sup>3</sup>/h appeared to be not necessary,
6. reduction of the operation and overhaul costs of the water treatment plant, the wastewater treatment plant and those of the heating system.

#### REFERENCES

- [1] AKOLZIN P. A. et al., *Spravočnye obščevo naznačenija*, Spravočnik Chimika Energetika, Vol. I (1960), Moscow.
- [2] *Power Generation Association. Heating Systems Operational Code*, Ramowa Instrukcja Eksploatacji Urządzeń Ciepłowniczych Zjednoczenia Energetyki, Warsaw 1964.

#### POŁĄCZONA METODA OCZYSZCZANIA WODY UZUPEŁNIAJĄCEJ DLA CELÓW CHŁODNICZYCH I GRZEWCZYCH

Opisano nową metodę oczyszczania wody uzupełniającej w cyklu chłodzącym i grzewczym. Zasilającą wodę surową poddaje się obróbce kwasami mineralnymi w celu zmniejszenia jej zasadowości, a następnie przepompowuje do chłodni kominowej. Następnie część ochłodzonej wody, po ogrzaniu wstępnym w kondensatorze i odpowietrzeniu, jest kierowana do systemu grzewczego. Podczas oczyszczania wody nie powstają ścieki. Przedstawione wyniki pochodzą z trzyletniego okresu eksploatacyjnego dużego zakładu przemysłowego. Omówiono wymagania stawiane jakości wody w systemie grzewczym.

#### GEMEINSAME AUFBEREITUNG DER SPEISEWÄSSER FÜR KÜHL- UND WÄRMEZWECKE

Beschrieben wird eine neuartige Wasseraufbereitungsmethode für Kühl- und Wärmezwecke. Das rohe Speisewasser wird mit Mineralsäuren angesäuert (zur Minderung der Alkalität) und in den Kühlturm gepumpt. Anschliessend wird ein Teil des abgekühlten Wassers — nach dem Vorwärmen im Kondensator und Entgasung — in das Wärmesystem geleitet. Während der Wasseraufbereitung entstehen keine Abwässer. Den hier niedergelegten Ergebnissen, liegt eine 3-jährige Betriebsperiode in einem großen Industrierwerk zugrunde.



## ОБЪЕДИНЁННЫЙ МЕТОД ОЧИСТКИ ДОБАВОЧНОЙ ВОДЫ ДЛЯ ХОЛОДИЛЬНЫХ И НАГРЕВАТЕЛЬНЫХ ЦЕЛЁЙ

В работе описан новый метод очистки добавочной воды в холодильном и нагревательном циклах. Сырая питательная вода подвергается обработке минеральными кислотами для уменьшения её основности, а затем перекачивается в башенный охладитель. Затем часть охлаждённой воды после предварительного нагрева в конденсаторе и удаления воздуха направляется в нагревательную систему. Во время очистки воды не образуются сточные воды. Представленные результаты происходят из трёхлетнего эксплуатационного периода крупного промышленного завода. Обсуждены требования, предъявляемые к качеству воды в нагревательной системе.