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PERFORMANCE OF POWER PLANT COOLING LAKES IN POLAND

Polish Institute of Meteorology and Water Management conducted a study to determine the effectiveness of cooling lakes in dissipating the waste heat from steam electric generating stations. The study was conducted at two locations: 1. the Konin Lake Complex, which consists of five lakes of a total surface area of 12.35 km² to provide cooling for two power plants with a total electrical capacity of 1783 MWe; 2. Rybnik Power station (800 MWe), which uses an impoundment of the Ruda River with a surface area of 4.65 km². Meteorological and power plant operating data were collected and analyzed to determine the rate of heat exchange at the cooling-lake surface. Over an annual cycle, the rate of heat exchange for both locations was approximately 16 kcal/m²-hr-°C. The values determined for the Polish locations compare favourably with empirical data reported in the technical literature.

1. INTRODUCTION

Data were collected by the Institute of Meteorology and Water Management on power plant operation and cooling-lake performance at two coal-fired steam electric generating complexes. Figure 1 indicates the location of these facilities. The Konin Lake Complex, located in central Poland, involves five lakes and two power plants with a total capacity of almost 1800 MWe. Rybnik is an 800 MWe plant in southern Poland near the Czechoslovakian border.

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Fig. 1. Location of Rybnik Power Plant and Konin Lakes
Rys. 1. Położenie Elektrowni Rybnickiej i Jezior Konińskich

2. KONIN LAKE COMPLEX

Power generation at Konin began in 1958 with the initial unit of the Konin Power Plant. By 1965, the plant had reached its present capacity of 583 MWe. In 1967, the first 200 MWe unit of the Pątnów Plant came on line, and by 1970 it reached a capacity of
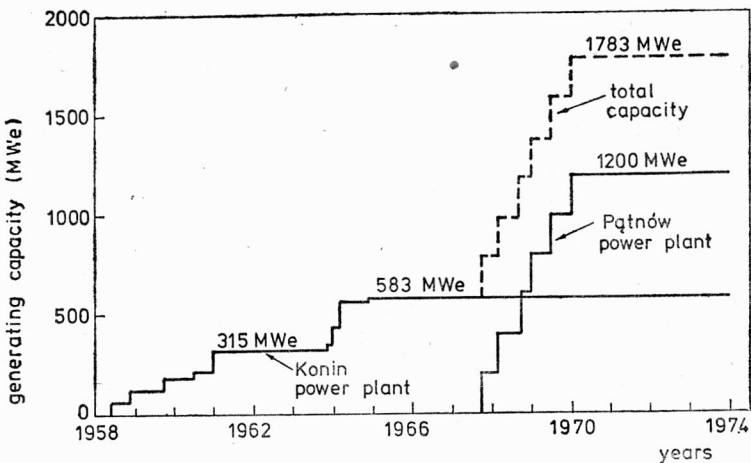

Fig. 2. Konin Lakes power station — capacity history
Rys. 2. Hydroelektrownia na Jeziorach Konińskich — wydajność i historia

1200 MWe. Figure 2 shows how the capacity of the two multi-unit plants increased from 1958 to 1974. The Pątnów Plant increased its capacity in 1974; however, the results presented here are based on data collected prior to 1974.

As the Konin and Pątnów Plants were put on line, the five Konin Lakes were utilized in a systematic way to dissipate the waste heat in the cooling water. Figure 3 provides an
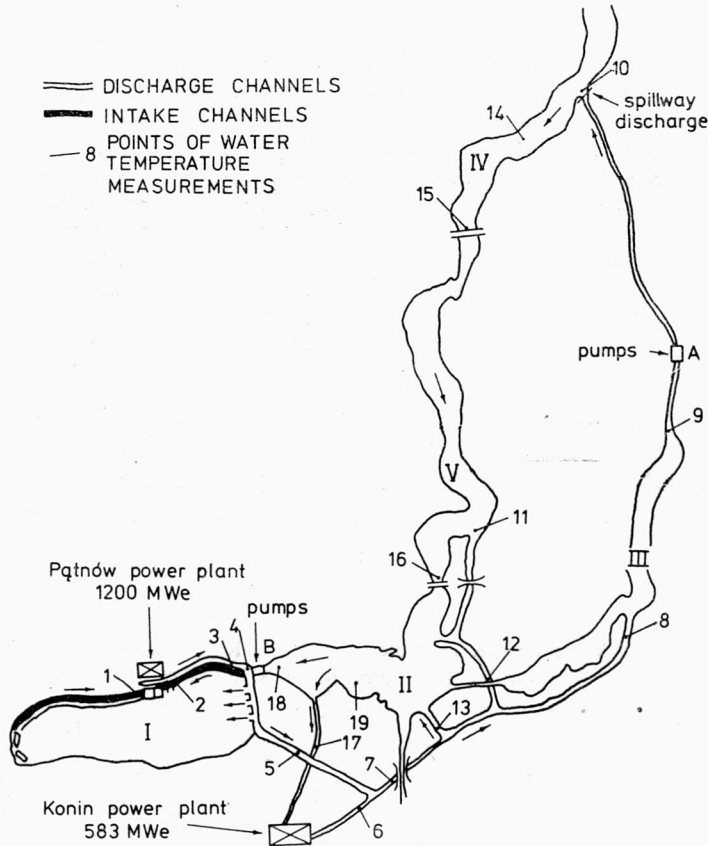

Fig. 3. Konin Lakes cooling system
Rys. 3. System chłodzący Jezior Konińskich

overall view of how the Konin Lakes are tied together to act as cooling lakes for the two power plants. Until 1964, only Pątnowskie Lake was used to handle the waste heat from the 315 MWe capacity of the Konin Plant (fig. 2). In 1964, when the Konin Plant was expanded to 583 MWe, Licheńskie Lake was added to the cooling system. The Pątnów Plant was added to the complex in 1967, and Gosławskie Lake was used to handle the first 600 MWe. In 1959, the Pątnów Plant began expanding from 600 to 1200 MWe, and the cooling circuit for the combined plants extended to all five lakes, adding Ślesińskie Lake and Wąsowsko-Mikorzyńskie Lake. The cooling water flow in the lake system is

gravitational, except for two locations where pump stations are employed. The first pump station is located on the Licheńskie-Ślesińskie channel (point A in fig. 3) and has a capacity of 23.6 m³/sec; the second pump station is installed on Pątnowskie Lake at the Pątnów Plant intake (point B in fig. 3) with a capacity of 25.1 m³/sec. Table 1 provides data related to power plant capacity and cooling-lake surface area for the four stages of development of the Konin Lakes cooling system.

Table 1

Plant capacity versus lake surface area
Wydajność elektrowni w zależności od powierzchni jeziora

Power plant capacity MWe	Lake surface area km²	Area/capacity ratio	
		km²/MWe	acres/MWe
315	2.77	8.79×10^{-3}	2.17
583	4.23	7.26×10^{-3}	1.79
1183	8.61	7.28×10^{-3}	1.80
1783	12.35	6.93×10^{-3}	1.71

The morphometric characteristics of the Konin Lakes given in tab. 2 indicate that two types of lakes are represented. Gosłwaskie and Pątnowskie Lakes are shallow, moraine lakes; Licheńskie, Ślesińskie, and Wąsowsko-Mikorzyńskie Lakes are deep, valley lakes. The shallow lakes are well mixed throughout the year, while the deep lakes undergo seasonal stratification.

Table 2

Morphometric characteristics of the Konin Lakes
Mierzalne parametry Jezior Konińskich

Lake	Area km²	Length km	Width km		Depth m		Storage capacity 10⁶ m³
			max.	av.	max.	av.	
Gosławskie (I)	4.38	4.0	1.5	1.0	3.5	2.1	9.1
Pątnowskie (II)	2.77	3.7	1.1	0.7	5.8	2.6	7.1
Licheńskie (III)	1.46	5.5	0.5	0.3	13.8	5.7	8.3
Ślesińskie (IV)	1.52	4.4	0.6	0.3	25.7	7.4	12.7
Mikorzyńskie (V)	2.22	6.6	1.0	0.4	38.0	11.9	28.9

3. RYBNIK COOLING LAKE

The cooling system for the Rybnik Plant includes a 4.65 km² impoundment on the Ruda River. As indicated in fig. 4, a diversion structure was constructed in the lake to act as an intake channel. The cooling water is discharged into the main body of the lake.
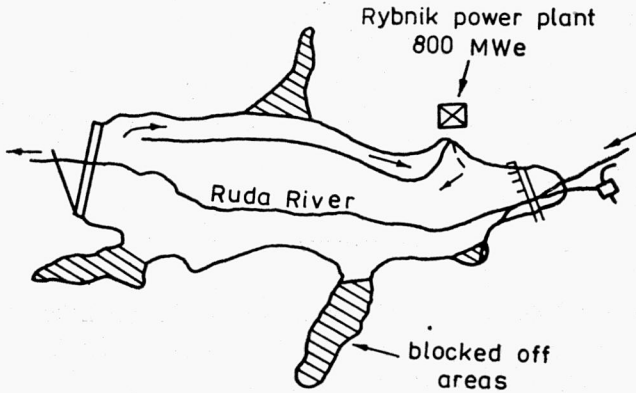
Fig. 4. Cooling lake system for Rybnik Power Plant
Rys. 4. System jezior chłodzących Elektrowni Rybnickiej

An active cooling surface area of 4.3 km² is obtained by blocking off four of the lake embayments where circulation is poor. Table 3 provides additional information on the Rybnik cooling lake.

Table 3

Parameters of the Rybnik Reservoir
Parametry zbiornika Rybnickiego

Total cooling surface area	4.65 km²
Active surface area	4.30 km²
Total storage capacity	21.4 × 10⁶ m³
Maximum length of reservoir	4. 35 km
Maximum width of reservoir	1.5 km
Maximum depth of reservoir	9.0 km
Mean depth of reservoir	4.6 m
Installed capacity of power plant	800 MWe

4. COOLING LAKE PERFORMANCE

For operating cooling lakes, the rate of waste-heat surface exchange can be determined by a simple energy balance, resulting in the following relationship:

$$K_w = \frac{H}{[(T_i+T_d)/2-T_nA}, \tag{1}$$

where:

K_w — waste heat surface exchange coefficient, kcal/m²-hr-°C,
H — heat discharged in cooling water, kcal/hr,
A — cooling lake surface area, m²,

T_i — power plant intake temperature, °C,
T_d — power plant discharge temperature, °C,
T_n — natural (or equilibrium) lake temperature, °C.

This equation is used to calculate an average heat exchange coefficient over the entire water-body surface.

4.1. KONIN LAKES

In order to determine the cooling effectiveness of the Konin Lakes, field studies were conducted. Data were collected in 1969, 1971, 1972, and 1973. For each power plant (i.e. Konin and Pątnów), average daily values of the following parameters were obtained:

power production, MWe,
intake temperature, °C,
discharge temperature, °C,
cooling water flow rate, m³/sec.

In addition, water-temperature data were collected at a number of locations throughout the lake system (fig. 3). Wind-speed data were also collected. Figure 5 provides a graphical representation of the data collected for the Konin Power Plant during the summer of 1971. These data are typical and are presented here to show the variability of various parameters.
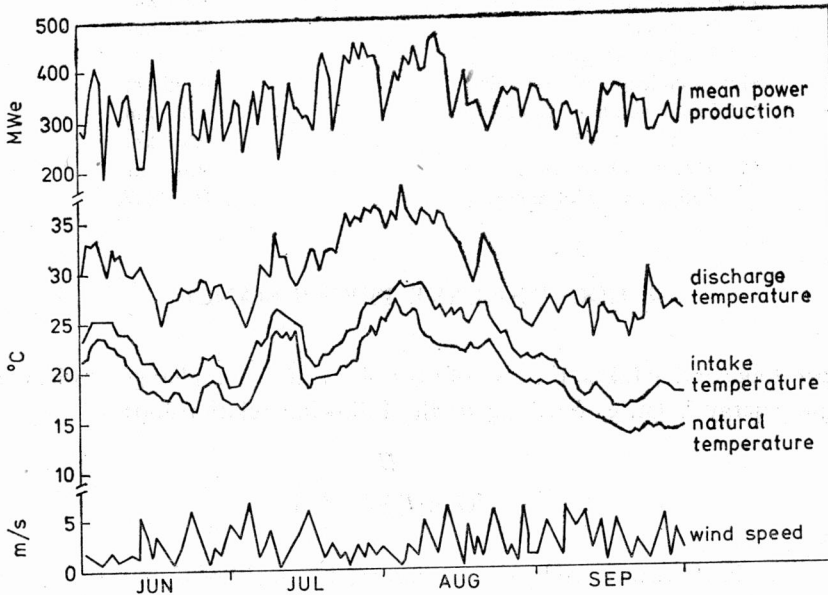

Fig. 5. Average daily cooling system parameters — Konin Power Plant, 1971
Rys. 5. Średnie dzienne parametry systemu chłodzącego Elektrowni Konińskiej, 1971

Equation (1) was used to calculate surface heat exchange coefficients K_w for various meterological conditions over an annual cycle for the Konin Lakes. Values of H were calculated from the power-plant load data using lake aeras A from tab. 2. Intake and dischange temperatures T_i and T_d were measured. The natural temperature T_n was obtained from surface measurements at Gopło Lake, a natural lake situated a few kilometers from the Konin Lakes. Since Gopło Lake is in the same climatic region, it was assumed that its surface temperature would be equivalent to the natural (or unheated) surface temperature of the Konin Lakes. Table 4 summarizes the results of these calculations. Average,

Table 4

Calculated values of K_w
Wartości K_w

| Lakes | K_w (kcal/m²-hr-°C) | | | | n^b |
	av.	min.	max.	S.D.^{a}	
Konin Lakes	15.6	12.1	21.1	2.4	22
Gosławskie Lake	16.2	10.2	23.6	3.5	26
Konin Lakes, less Gosławskie Lake	15.1	10.7	20.8	2.9	22
Rybnik Reservoir	16.5	12.7	20.3	1.8	34

a — sample standard deviation.
b — sample size.

minimum, and maximum values are given, as well as the sample standard deviation S.D. and the sample size n. Note that separate calculations were completed for Gosławskie Lake. Since this lake receives the direct discharge from the large Pątnów Plant, it would be expected that its temperature is higher, thus that it dissipates the waste heat at a higher rate; this is confirmed by the higher K_w values.

4.2. RYBNIK RESERVOIR

Power plant operating data and appropriate meteorological data were also collected for the Rybnik Station. The values of K_w were also calculated. For Rybnik, instead of measured natural temperatures, we used calculated equilibrium temperatures. Equilibrium--temperature computations were based on a heat balance of the reservoir under natural meteorological conditions. Reservoir inflows and discharges were also considered. These equilibrium temperatures were compared to actual temperatures measured in the blocked off areas (fig. 4) which were unaffected by the cooling-water discharges. This "verification" process confirmed the general accuracy of the calculated equilibrium temperatures. Table 4 provides the summary statistics for K_w for Rybnik Reservoir.

4.3. COMPARISON WITH OTHER EMPIRICAL COEFFICIENTS

The technical literature on temperature prediction contains a number of empirical relationships for calculating heat exchane coefficients (1). Edinger and Geyer [2] present the general expression:

$$K = 3.2 + f_1(T_n)f_2(W),\qquad(2)$$

where:

K — heat exchange coefficient, kcal/m²-hr-°C,

$f_1(T_n)$ — empirical function based on natural (or equilibrium) temperature, $T_n(°C)$,

$f_2(W)$ — empirical evaporative mass-tranfer function based on wind speed, W(m/s).

In units consistent with this paper, equation (2) was used to claculate the values of K for four different functions $f_2(W)$ for both the Konin Lakes and Rybnik Reservoir. The following average values of T_n and W were used:

VARIABLE	KONIN	RYBNIK
$\overline{W}$ (m/s)	3.05	1.64
$\overline{T}_n$ (°C)	14.0	17.4

Table 5 presents the results of these calculations. The average, minimum, maximum, and 95% Confidence Interval (CI) for the values of K_w determined by the Polish study are also presented.

Table 5

Comparison of K values
Porównanie wartości K

Source of f_2 (W) function	K (kcal/m²-hr-°C)	
	Konin Lakes	Rybnik Reservoir
Lake Hefner [2]	15.9	11.1
Lake Colorado City [2]	22.2	15.0
Meyer [2]	24.8	23.4
Brady et al. [3]	21.4	19.7
POLISH STUDY		
Average	15.6	16.5
Min., max.	12.1, 21.1	12.7, 20.3
95% C I	(10.6—20.6)	(12.8—20.4)

As indicated by tab. 5, the K_w for Rybnik Reservoir is consistent with the values calculated by the Lake Colorado City [2] and Brady [3] functions. For the Konin Lakes, the Lake Hefner [2] function matches the measured value. Thus, only the values of K obtained

by using the Meyer [2] function fall outside the 95% CI for the values of K_w measured on the Polish lakes. Given the range of K values obtained by using the various empirical $f_2(W)$ functions, the results reported herein are very representative of and comparable to the past studies.

5. SUMMARY AND CONCLUSIONS

Data on power plant operations and meteorology were collected at two power generating/cooling reservoir complexes in Poland. Analyses of the heat transfer from the cooling lakes were conducted. These analyses confirmed that heat transfer coefficients were consistent with the past studies.

The following conclusions were obtained:

1. A complex integrated system of natural lakes (i.e. the Konin Lakes) can be used as cooling reservoirs for steam electric generating stations.

2. The heat transfer performance of such a complex system can be determined from standard field measurements.

3. Data collected on operating power-plant cooling reservoirs confirm the general accuracy of heat-transfer rates developed in past studies.

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WYDAJNOŚĆ JEZIOR CHŁODNICZYCH ELEKTROWNI W POLSCE

Polski Instytut Meteorologii i Gospodarki Wodnej przeprowadził badania dla wyznaczenia efektywności jezior chłodzących w rozpraszaniu ciepła odlotowego z pary zakładów energetycznych. Badania były prowadzone w dwóch miejscach: 1. kompleksie Jezior Konińskich składających się z 5-ciu jezior o całkowitej powierzchni 12,35 km², zapewniających chłodzenie dwom elektrowniom o całkowitej wydajności 1783 megawaty, 2. elektrowni Rybnik, która korzysta ze spiętrzenia rzeki Rudy o powierzchni 4,65 km². Dane meteorologiczne i operacyjne elektrowni zostały zebrane i przeanalizowane, aby wyznaczyć szybkość wymiany ciepła na powierzchni jeziora chłodzącego. W cyklu rocznym szybkość wymiany ciepła w obu miejscowościach wynosiła w przybliżeniu 16 kcal/m² godz. °C. Wartości wyznaczone dla polskich miejscowości są w dobrej zgodności z danymi w literaturze technicznej.

WÄRMEABGABE IN KÜHLSEEN EINIGER POLNISCHER KRAFTWERKE

Im Rahmen des polnischen Instituts für Meteorologie und Wasserwirtschat (IMGW) untersuchte man den Abkühlverlauf des Wassers in Kühlseen. Die Untersuchungen wurden an zwei Anlagen geführt. Das 5-Seenkomplex von Konin mit einer Gesamtfläche von 12,35 km² wird von zwei Kraftwerken mit einer Summenkapazität von 1783 MW genutzt. Die Kühlwässer des Kraftwerks von Rybnik, werden in ein Staubecken an der Ruda mit einer Fläche von 4,65 km² eingeführt. An beiden Orten war die Wärmeabgabe von der Wasseroberfläche im Jahreszyklus nahezu gleich und betrug etwa 16 kcal/m²h°C. Diese in Polen festgestellten Werte, stimmen mit den Literaturangaben gut überein.

ПРОИЗВОДИТЕЛЬНОСТЬ ХОЛОДИЛЬНЫХ ОЗЁР ЭЛЕКТРОСТАНЦИЙ В ПОЛЬШЕ

Польский институт метрологии и водного хозяйства произвёл исследования для определения эффективности охлаждающих озёр в рассеянии отработанного тепла из пара электрических установок. Исследования проводились в двух местах: 1) в комплексе Конинских озёр, состоящем из пяти озёр общей площадью 12,35 км², обеспечивающих охлаждение двум электростанциям общей производительности 1783 мегавата, 2) на электростанции Рыбник, которая использует подъём воды реки Руды, площадью 4,65 км². Метрологические и операционные данные электростанции были собраны и проанализированы для определения скорости теплообмена на поверхности охлаждающего озера. В годовом цикле скорость теплообмена в обоих местах составляла приблизительно 16 ккал/м²ч°C. Значения, определённые для вышеотмеченных мест, вполне соответствуют данным по технической литературе.