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J. R. DOJLIDO, T. SUCHECKA, W. ŻBIKOWSKI*

GAS SUPERSATURATION OF FLOWING WATERS IN POLAND

Investigations on the degree of gas supersaturation of the Vistula water in the area of the Kozienice power plant, were conducted, of the San river water in the vicinity of the Stalowa Wola power plant and of water in the vicinity of six water dams situated in the southern areas of Poland. The gas supersaturation of water, the concentration of dissolved oxygen and temperature have been measured.

In the Vistula water near Kozienice measurements of chlorophyll, total and organic seston were made.

The influence of thermal water discharge from the power plant and the dam constructions on the gas supersaturation was small. The most significant correlation has been observed between the oxygen supersaturation and photosynthesis process.

1. INTRODUCTION

Supersaturation of water with gases exert a disadvantageous effect on water organisms. At first this phenomenon was known only in cases of pisciculture in aquaria and fish hatcheries. Supersaturation of water with gases led to the so-called gas-bubble disease and consequently, to fish mortality. This phenomenon was observed by GORDHAM [4] as early as in 1898, but for many years, its meaning was only theoretical. In the recent years, however, the problem has become important because of the increasing number of the sources of water supersaturation and their negative effects.

The supersaturation of water with oxygen and nitrogen, is due to rapid changes of the temperature and pressure of water. This phenomenon is chiefly observed in the regions where heated water is discharged from power stations, and in the neighbourhood of dams. The supersaturation appears first of all when the dams are high and the water reservoirs below the dam are deep. Water flowing over the crest catches entrains air particles which are introduced under a high pressure below the water surface. This water flows very deep, where under heightened pressure the air is dissolved. When the water leaves deep layers and returns to the surface, the pressure suddenly drops and the water becomes supersatura-

* Institute of Meteorology and Water Management, Warsaw, Poland.

ted with gases. Gas supersaturation of water occurs frequently below power stations with open cooling systems, due to a sudden heating of initially cool water. Oxygen supersaturation of water may also take place due to photosynthesis, especially in case of water blooming.

So far in Poland no investigations on gas supersaturation of water have been conducted. This paper presents the results obtained from the measurements of the degree of water saturation with gases, performed near selected power stations and water dams.

2. THE OCCURRENCE OF WATER SUPERSATURATION WITH GASES

The phenomenon of supersaturation with gases up to 114% was observed near the dam Goose on the river Snake, where the water flows over the dam 30 m high, falling to a deep reservoir [2]. In the case of the dam Ruedi on the river Frying Pan the saturation with nitrogen amounted to 116% [3]. Near the dam Morrow Point, ca 150 m high, on the river Gunnison, the observed supersaturation with nitrogen reached 112% [3].

In the regions of power stations with open cooling systems one observed some cases of bubble disease of hish due to the supersaturation of water with gases. Marshall power station taking cool water from the hypolymnion of the Norman lake heated it sometimes by 15.8°C. In the lake water to which the heated water was discharged the occurring supersaturation with nitrogen caused sometimes bubble disease of many fish species [1].

Similar phenomena have been observed in the case of nuclear power station Millstone [3]. Water uptaken at temperature of 7.2°C was heated to 21.1°C. Although such temperatures do not exceed the tolerance limit for fish, the mortality of about 15.000 fishes occurred in consequence of supersaturation of water with gases.

3. MEASUREMENT OF SATURATION WITH GASES

This measurement was conducted by means of the Weiss saturometer [6]. Its basic part consists of a silicone gas-permeable tubing 120 mm long with inside diameter of 0.3 mm (fig. 1). The measurement was conducted in the following way: Sensor of the saturometer is introduced below the water surface and by means of an injector the pressure on manometer is increased. Then the valve is closed, and the reading of the manometer is taken not earlier than after 20 min. i.e. when the indicating needle of the pressure gauge is stabilized (the sensor should be slightly moved). Then the valve is opened and after the indicating needle is stabilized the pressure is read again.

At the same time the water temperature, atmospheric pressure and concentration of dissolved oxygen are measured. The calculations are performed according to the formula

$$C_1 = \frac{P_b + \Delta P - P_{H_2O}}{P_b} \cdot 100\%$$

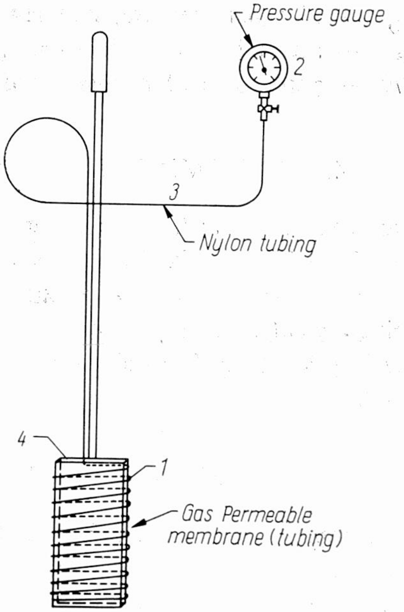

Fig. 1. Layout of Weiss' saturometer:
1 — sensitive element, silicon gas permeable tubing, *2* — pressure gauge, *3* — nylon tubing, *4* — metal frame

Rys. 1. Schemat saturatora Weissa
1 — czujnik, przewody silikonowe przepuszczalne dla gazu, *2* — manometer ciśnieniowy, *3* — przewody nylonowe, *4* — rama metalowa

where

C_1 — total saturation with gases, %,
P_b — barometric pressure, mm Hg,
ΔP — difference in the pressure gauge reading, mm Hg,
P_{H_2O} — pressure of water vapor, mm Hg

and

$$C_2 = \frac{m \cdot 0.7}{n} \cdot 100\,\%$$

where

C_2 — oxygen saturation,
m — determined oxygen concentration, mg/dm³,
n — oxygen concentration at 100% saturation in the given temperature, cm^3/dm^3 [6],
0.7 — conversion factor (from mg/dm^3 into cm^3/dm^3).

$$P_{O_2} = \frac{m \cdot 0.7}{B_{O_2}} \cdot 0.76, \text{ mm Hg},$$

$$P_{N_2} = P_b + \Delta P - (P_{O_2} + P_{H_2O}), \text{ mm Hg},$$

$$C_3 = \frac{P_{N_2}}{P_b \cdot 0.79} \cdot 100\,\%$$

where

P_{O_2} — oxygen pressure, mm Hg,
B_{O_2} — Bunsen coefficient for oxygen [6],

P_{N_2} — nitrogen pressure, mm Hg,
C_3 — saturation with nitrogen, %,
0.79 — percentage of nitrogen and argon in dry air.

4. DETERMINING OF CHLOROPHYLL CONTENT

The sampled water was filtered through the filtre made of glass fibre (Whatman GF83). Filters together with material filtred in vivo were dried at temperature $\leq 4°C$, ground in a mortar and then the pigments were extracted with 90% solution of acetone. The extract was centrifugated at 7000 rev/min and the extinction was measured on spectrophotometer at the wavelength 665 nm. The chlorophyll concentration was calculated from the Lorenzen formula [5].

5. GRAVIMETRIC ANALYSIS OF SESTON

Seston samples were obtained by filtrating the water examined through filters made from glass fibre (Whatmann GF83). The material thickened on filters was dried at temperature of 105°C and weighed. The content of organic substances in seston (the so-called organic seston) was determined by igniting the dried sample at 550°C, and then by weighing.

6. RESULTS OF INVESTIGATIONS

The measurements of water saturation with gases were conducted from October 1975 to December 1976 in the following sites: Vistula river near the power plant Kozienice, the San river near the power plant Stalowa Wola and water impoundments: Leśna on the Kwisa river, Pilchowice on the Bóbr river, Lubachów on the Bóbr river, Tresna on the Soła river, Rożnów on the Dunajec river and Solina on the San river.

6.1. THE VISTULA RIVER

The degree of water gas saturation was examined above the power plant, in discharge channel (cooling water) and below the power plant at the distance of about 2000 m from the site of heated water discharge. The temperature of water in Vistula above the power plant varied from 0.4 °C to 25.2 °C. The temperature of cooling water in discharge channel was much higher 17.0–36.0°C what caused the increase of water temperature below the power plant which was ranging from 5.0 to 26.4 °C. The total gas saturation of Vistula water was changing slightly, oscillating near the 100% of saturation; the lowest saturation amounted to 95.8%, the highest — to 114.5%.

The saturation with nitrogen gave similar values, ranging from 91.0% to 109.4%. The total gas saturation of water was distinctly higher in summer being correlated with the saturation with oxygen in summer which reached 199% and in winter decreased to 80.8% (figs. 2, 3, 4).

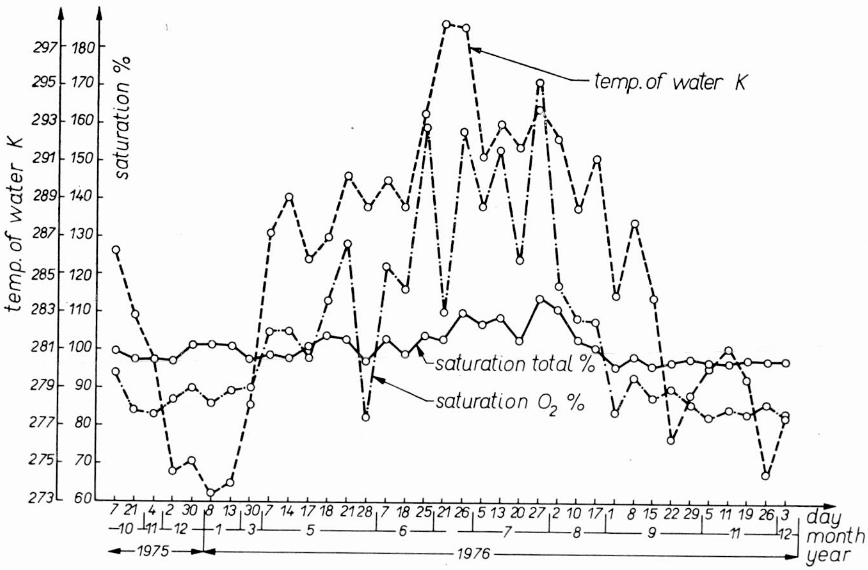

Fig. 2. Changes of saturation degree in Vistula river water above the power plant Kozienice
Rys. 2. Zmiany stopnia nasycenia wody Wisły w pobliżu Kozienic

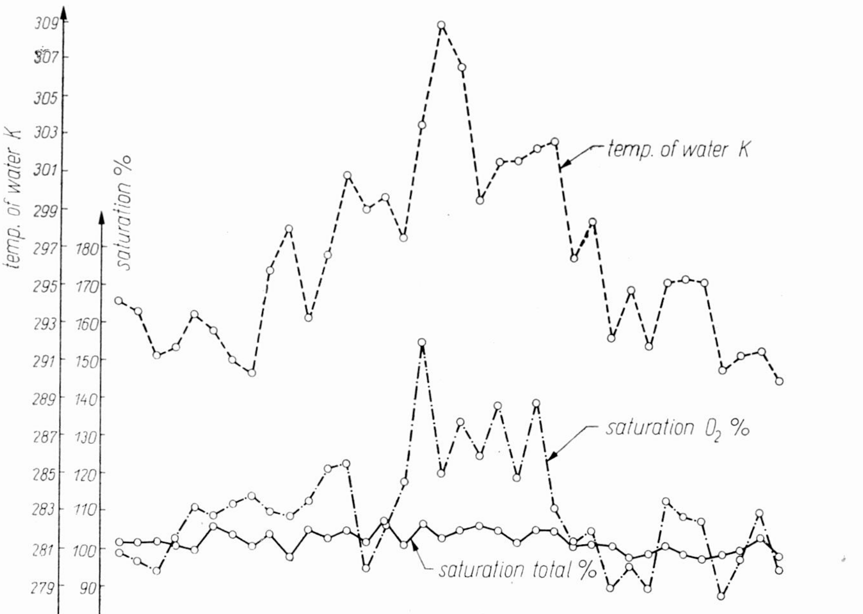

Fig. 3. Changes of the saturation degree of the Vistula river water in discharge channel of the power plant Kozienice
Rys. 3. Zmiany stopnia nasycenia wody Wisły w kanale odpływowym elektrowni Kozienice

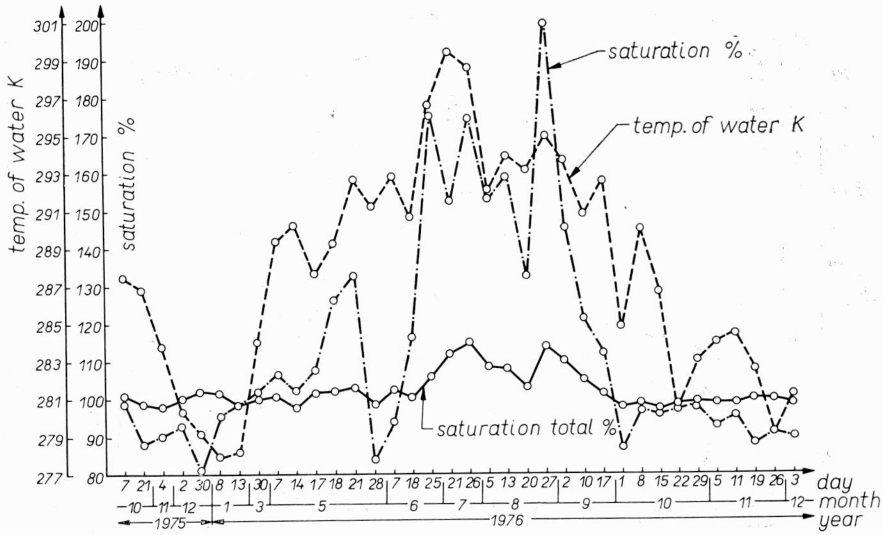

Fig. 4. Changes of saturation degree in Vistula river water below the power plant Kozienice
Rys. 4. Zmiany stopnia nasycenia wody Wisły poniżej elektrowni Kozienice

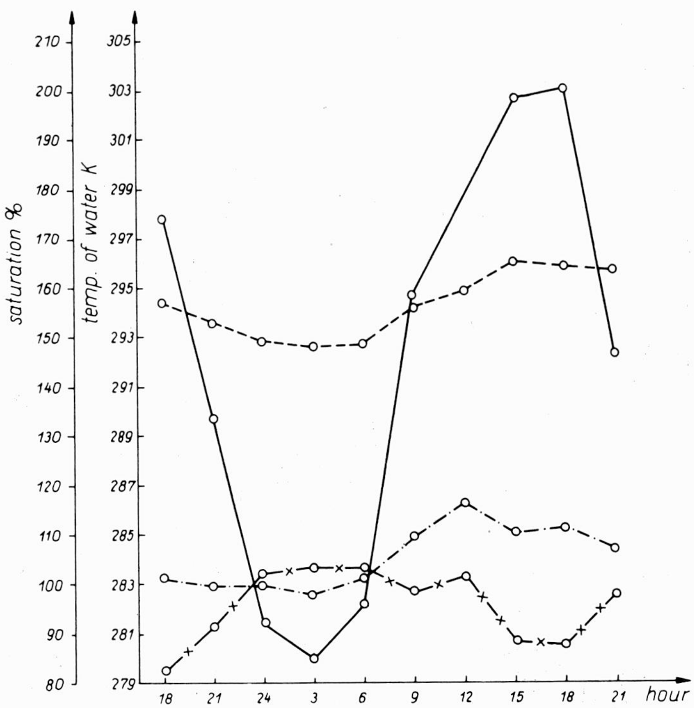

Fig. 5. Circadian changes of the saturation degree of Vistula river water below the power plant Kozienice
Rys. 5. Zmiany dobowe stopnia nasycenia wody Wisły poniżej elektrowni Kozienice

In cooling water in the discharge channel the saturation with oxygen was lower, thus proving that water passing through the cooling system is being degased.

24 hr investigations of the gas saturation degree of the water in the river Vistula, performed in July 1976 showed the highest changes in oxygen saturation. The changes of oxygen saturation are conditioned by the time of the day; the minimum saturation was stated in night and the maximum in late afternoon (fig. 5).

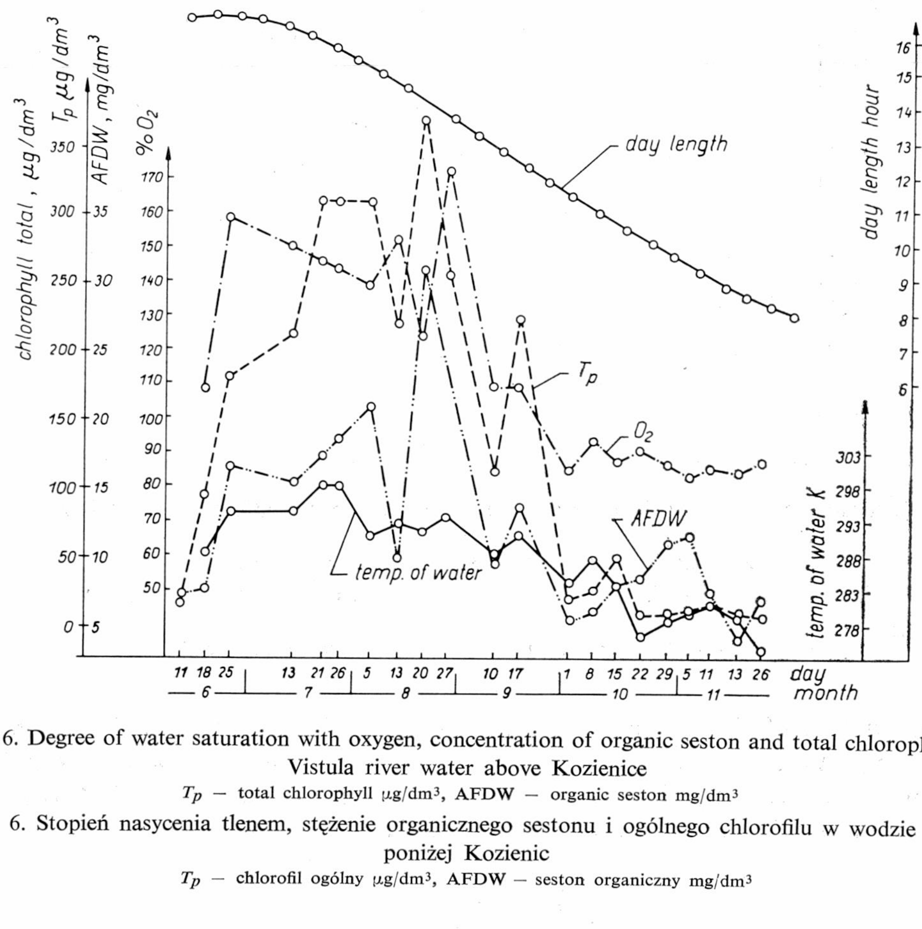

Fig. 6. Degree of water saturation with oxygen, concentration of organic seston and total chlorophyll in Vistula river water above Kozienice

Tp — total chlorophyll µg/dm³, AFDW — organic seston mg/dm³

Rys. 6. Stopień nasycenia tlenem, stężenie organicznego sestonu i ogólnego chlorofilu w wodzie Wisły poniżej Kozienic

Tp — chlorofil ogólny µg/dm³, AFDW — seston organiczny mg/dm³

In order to find the reasons of the above circadian and annual variations in the oxygen concentration there were additionally performed the determination of the chlorophyll content and gravimetric analysis of seston. The concentrations of total chlorophyll were characterized by a high variability, from 17.6 µg/dm³ in autumn (in winter chlorophyll was not determined) to 371.5 µg/dm³ (fig. 6). There is a distinct relationship between the degree of oxygen saturation and the contents of seston and chlorophyll in water. The influence of phytoplanktone on the oxygen concentration in the water of the river Vistula can be determined by analysing the results of 24 hr measurements, conducted in July 1976 (fig. 7).

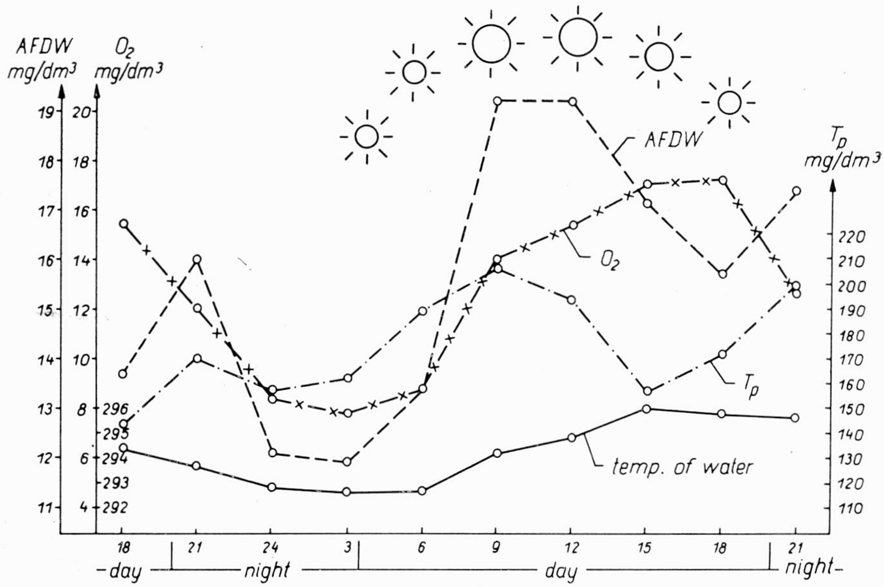

Fig. 7. Circadian changes in organic seston and total chlorophyll concentrations in the Vistula water below Kozienice,

Tp — total chlorophyll μg/dm³, AFDW — organic seston, mg/dm³

Rys. 7. Zmiany dobowe nasycenia organicznego sestonu i ogólnego chlorofilu w wodzie Wisły poniżej Kozienic

Tp — ogólny chlorofil μg/dm³, AFDW — organiczny seston mg/dm³

The contents of bioseston and chlorophyll increase with the increasing insolation and water temperature, consequently the water is rapidly supersaturated with oxygen. This relation may be distinctly illustrated by the changes in the values of coefficients f_1 and f_2 versus the saturation of water with oxygen (fig. 8):

$$f_1 = \frac{C_3 - 100\%}{S_0},$$

$$f_2 = \frac{C_3 - 100\%}{\mathrm{Chl}_a}$$

C_3 — saturation with oxygen, %,
S_0 — content of organic seston, mg/dm³,
Chl_a — content of chlorophyll „*a*", μg/dm³.

These coefficients may be taken as a measure of photosynthetical efficiency of phytoplankton, which influences directly concentration of oxygen in water.

From the results obtained it may be stated that the degree of water saturation with

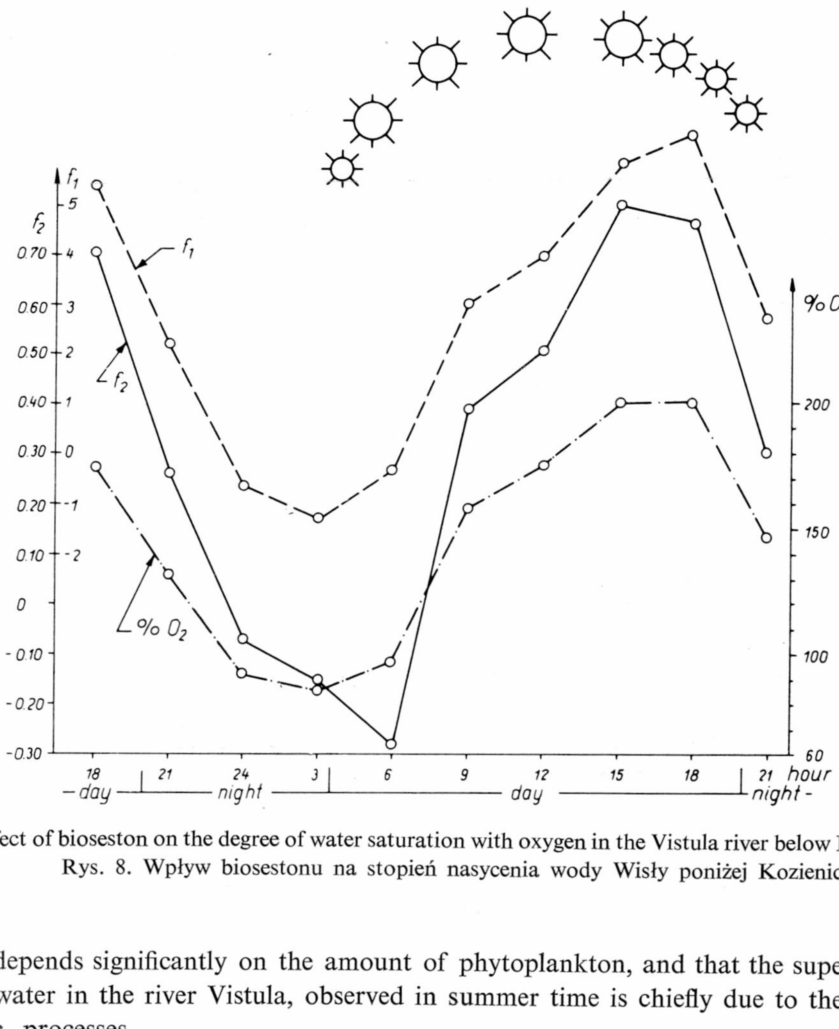

Fig. 8. Effect of bioseston on the degree of water saturation with oxygen in the Vistula river below Kozienice
Rys. 8. Wpływ biosestonu na stopień nasycenia wody Wisły poniżej Kozienic

oxygen depends significantly on the amount of phytoplankton, and that the supersaturation of water in the river Vistula, observed in summer time is chiefly due to the photosynthetic processes.

6.2. THE SAN RIVER

Results of the investigation on gas saturation of water conducted near the power plant Stalowa Wola, are shown in table 1. The temperature of water in the river due to the discharge of heated water increased by 2.6–6.3 °C reaching in summer 34.8° C. The changes in the total gas saturation due to season of the year or to the discharge of heated water were not significant. A slightly higher gas saturation observed in summer is related to the increased oxygen saturation, which in June 1976 increased maximally to 161.3 %.

Table 1

Gas saturation of San river water in the vicinity the power plant

Date	Station	Water temp. °C	D.O. mg/dm³ O_2	Saturation %		
				total	nitrogen	oxygen
November, 1975	1	3.0	11.6	97.3	99.9	86.3
	2	13.8	10.0	100.4	101.3	96.7
	3	11.2	9.4	97.8	100.9	85.8
April, 1976	1	8.1	10.0	98.1	102.8	84.7
	2	21.7	8.8	99.8	97.2	100.3
	3	16.4	9.4	99.7	99.0	96.2
June, 1976	1	23.0	13.8	101.9	86.9	161.3
	2	34.8	7.6	101.5	100.6	109.7
	3	26.5	7.8	102.8	104.1	100.7

Station 1 — above the power plant
Station 2 — cooling water from discharge channel
Station 3 — below the power plant

6.3. THE IMPOUNDMENTS

The measurements of water gas saturation were carried out below and above six dams in the submountaineous districts of South Poland. The height of dams ranged from 20 to 60 m. During the measurements levels of water were not very high and the water did not overflow the overfall crests. The water flew through lower sluides or passed through turbines of hydroelectric power stations. Results of measurements are presented in tables 2, 3 and 4.

Below the dams the water temperature was always lower than that above the dams. The total water saturation with gases near dams varied from 90.2 to 115.5 %. In summer the saturation decreased after the water had passed the dam (table 4).

Similar effect was also observed in the saturation of water with dissolved oxygen. The saturation decreased from 176.8 % to 100.7 % in case of Lubachów reservoir, and from 70 to 11 % in Pilichowice reservoir. Increased concentrations of dissolved oxygen usually were in correlation with the increased values of total gas saturation of water, which proves that the oxygen is the chief factor responsible for the changes in the degree of water saturation with gases.

Table 2

Gas saturation of impoundment water November 1975

Reservoir	Station	Water temp. °C	D.O. mg/dm³O_2	Saturation%		
				total	nitrogen	oxygen
Leśna	1	7.2	8.4	96.6	103.1	69.7
	2	6.0	9.6	97.6	102.4	77.2
Lubachów	1	6.9	8.0	94.9	101.8	65.8
	2	5.0	8.6	97.4	104.6	67.4
Tresna	1	6.9	10.0	96.4	99.4	82.2
	2	6.4	9.6	97.1	101.6	78.0
Rożnów	1	7.0	10.2	97.4	100.2	84.1
	2	7.0	10.2	96.3	98.9	84.1
Solina	1	8.4	8.4	93.9	98.9	73.2
	2	8.3	8.6	96.5	101.9	73.2

Station 1 — above the dam,
Station 2 — below the dam.

Table 3

Gas saturation of impoundment water April 1976

Reservoir	Station	Water temp. °C	D.O. mg/dm³O_2	Saturation %		
				total	nitrogen	oxygen
Leśna	1	8.8	11.9	99.2	97.8	102.6
	2	7.9	11.4	99.4	100.0	96.1
Pilchowice	1	9.6	6.6	98.4	109.4	58.0
	2	7.2	5.7	97.7	112.5	47.3
Lubachów	1	7.5	9.4	99.3	103.7	78.5
	2	6.8	12.5	100.1	97.3	102.6
Tresna	1	8.6	11.3	99.3	98.6	96.9
	2	7.5	11.2	99.1	99.6	93.6
Rożnów	1	8.8	11.0	99.1	99.4	94.8
	2	7.4	10.2	99.1	102.2	85.0
Solina	1	5.2	11.2	99.1	101.2	88.3
	2	3.2	10.8	98.8	103.5	80.8

Station 1 — above the dam.
Station 2 — below the dam.

Table 4

Gas saturation of impoundment water June 1976

Reservoir	Station	Water temp. °C	D.O. $mg/dm^3 O_2$	Saturation %		
				total	nitrogen	oxygen
Leśna	1	25.0	9.6	101.5	97.5	116.5
	2	14.8	8.8	90.2	91.1	87.0
Pilchowice	1	26.6	5.6	100.5	108.9	70.0
	2	15.1	1.1	88.5	109.1	11.0
Lubachów	1	23.4	15.0	115.5	99.3	176.8
	2	13.4	10.5	100.6	100.3	100.7
Tresna	1	21.4	10.2	103.5	100.1	115.5
	2	19.0	7.0	100.9	107.5	75.6
Rożnów	1	22.6	10.8	108.0	103.7	125.2
	2	17.2	7.3	95.0	100.2	75.9
Solina	1	20.0	10.0	102.1	99.5	110.2
	2	10.3	9.6	99.7	102.9	85.7

Station 1 — above the dam,
Station 2 — below the dam.

7. CONCLUSIONS

The measurements of the gas saturation of river water, performed in the neighbourhood of power plants with an open coolling system and in the areas of dams, have shown that the total saturation reaches 115%, and the oxygen saturation — 200%. The variations in the total saturation were conditioned by the changes in the degree of oxygen saturation. High supersaturation of water with oxygen, occurring during vegetation season was due to photosynthesis. A distinct correlation has been stated between the degree of saturation with oxygen and contents of organic seston (chiefly phytoplankton) in water. The relation between supersaturation of water and chlorophyll concentration was particularly distinct.

The effect of heated water discharge from the power plant on the gas saturation of water was small. After the water had passed through the cooling system of power plant the degree of saturation with gases slightly decreased, while in the river below, the saturation of water with oxygen increased again due to a higher intensity of the photosynthesis.

In water near dams the oxygen concentration decreased after the water had passed the dam, which was due to the flow of water through lower sluices or turbines of hydro-electric power stations. No negative effect of gas supersaturation of water on the state of ichtiofauna has been observed during the investigations.

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NASYCENIE GAZAMI WÓD PŁYNĄCYCH W POLSCE

Przeprowadzono badania stopnia nasycenia gazami wody Wisły w pobliżu elektrowni Kozienice, wody Sanu w rejonie elektrowni Stalowa Wola i wody w pobliżu sześciu zapór usytuowanych w południowej części Polski.

Wykonano pomiary całkowitego nasycenia wody gazami, zawartości tlenu rozpuszczonego oraz temperatury. W przypadku badania Wisły wykonywano pomiary zawartości chlorofilu, sestonu ogólnego i organicznego.

Maksymalne całkowite przesycenie gazami wody Wisły wyniosło 116%, a maksymalne przesycenie tlenem 20%. Wpływ zrzutu wód podgrzanych na nasycenie wody gazami był niewielki. Po przepłynięciu wody przez system chłodzenia elektrowni obserwowano mały spadek stopnia nasycenia wody gazami. W rzece poniżej elektrowni zaobserwowano znaczny wzrost nasycenia wody tlenem, co można było przypisać działaniu procesu fotosyntezy, stymulowanemu wzrostem temperatury w wyniku zrzutu wód podgrzanych.

Maksymalne całkowite przesycenie wody Sanu wynosiło 102,8%, a nasycenie tlenem 161%.

Pomiary nasycenia gazami wody w pobliżu zapór przeprowadzono w okresach, gdy woda przepływała przez upusty dolne lub przez turbiny generatorów elektrowni wodnych. W większości przypadków przepływ wody przez zaporę powodował zmniejszenie całkowitego nasycenia wody gazami i spadek nasycenia tlenem rozpuszczonym. Duże zawartości tlenu w wodzie powyżej zapór (do 177% nasycenia) powodowane procesem fotosyntezy zachodzącym w okresie wegetacyjnym, po przejściu wody przez zaporę ulegały gwałtownemu obniżeniu.

Stwierdzono, że zmiany całkowitego nasycenia wody gazami były głównie uzależnione od zmian stężenia rozpuszczonego tlenu; zawartości rozpuszczonego azotu w wodzie ulegały małym wahaniom. Zaobserwowano, że główną przyczyną dużego przesycenia wody tlenem był proces fotosyntezy.

SÄTTIGUNG VON POLNISCHEN FLIESSENDEN GEWÄSSERN MIT GASEN

Untersucht wurde die Sättigung mit Gasen der Wisła-Wässer (Weichsel) in der Nähe eines Großkraftwerkes, die Wässer des Sanes, ebenso in der Nähe eines Elektrizitätswerkes und die Wässer aus sechs Staubecken im Süden Polens.

Gemessen wurde die allgemeine Sättigung mit Gasen, der Sauerstoffgehalt und die Temperaturen. Im Wisła-Wasser wurde noch die Chlorofilmenge, die Menge des allgemeinen und des organischen Sestons untersucht.

In den Wisła-Wässern wurde eine maximale Übersättigung mit Gasen von 116% festgestellt, die maximale Übersättigung mit Sauerstoff betrug 200%. Der Einfluß der eingeführten Warmwässer auf die Sättigung war gering. Der Gasgehalt im Wasser war nach der Kühlung nur unwesentlich herabgesetzt. Unterhalb des EW war im Flußwasser ein enormer Anstieg des Sauerstoffs feststellbar, was durch die stimulierte Photosynthese zu erklären wäre.

Die maximale Übersättigung des San-Wassers betrug 102,8%, der maximale Sauerstoffgehalt war 161%.

Die Messungen an den Talsperren wurden sowohl beim Durchlauf des Wassers durch die Wasserkraftturbinen durchgeführt als auch dann, wenn es durch die Bodenabläße floß. In überwiegenden Fällen bewirkte der Durchfluß durch die Staubecken ein Absinken der gelösten Gasmenge, Sauerstoff inbegriffen. Hohe Sauerstoffgehalte oberhalb der Talsperren (bis zu 177% Sättigung) — durch Photosynthese bewirkt — sanken nach der Talsperre rasch ab. Man stellte fest, daß zum Absinken der gelösten Gase die wechselnden Sauerstoffmengen am meisten beitragen. Der Stickstoffgehalt schwankt in schmalen Bereichen.

ГАЗОНАСЫЩЕННОСТЬ ПРОТОЧНОЙ ВОДЫ В ПОЛЬШЕ

Исследовалась степень насыщения газами воды Вислы, Сана и воды вблизи шести плотин, расположенных в южной части Польши. Выполнены измерения полного газонасыщения воды, содержания растворенного кислорода и температуры. При анализе воды реки Вислы было определено содержание хлорофилла, а также общего и органического сестонов.

Максимальное полное насыщение газами воды Вислы составило 116%, а максимальное пересыщение кислородом — 200%. Влияние сброса подогретых вод на насыщение воды газами было небольшим. После перехода воды через систему охлаждения электростации наблюдалось малое снижение газонасыщенности. В реке ниже электростанции отмечен значительный рост насыщения воды кислородом, что можно связывать с воздействием процесса фотосинтеза, стимулируемым ростом температуры в результате спуска подогретой воды.

Максимальное полное пересыщение воды Сана составило 102,8%, а насыщение кислородом 161%.

Измерения насыщения газами у плотин производились при протекании воды через нижние спуски или турбины генераторов гидроэлектростанций. В большинстве случаев протекание воды через плотину вызывало снижение полного насыщения воды газами и падение насыщения растворенным кислородом. Большое содержание кислорода в воде выше плотины (до 177% насыщения), вызываемое процессом фотосинтеза в вегетационный период, снижалось после перехода через плотину очень резко.

Обнаружено, что изменения в полном насыщении воды газами зависят, главным образом, от изменений в концентрации растворенного кислорода; содержание растворенного азота в воде подвергалось небольшим колебаниям. Установлено, что главная причина большого пересыщения воды кислородом заключалась в процессе фотосинтеза.