Teka Kom. Ochr. Kszt. Środ. Przyr. – OL PAN, 2009, 6, 368–373

EMISSION OF METHANE FROM SEDIMENTS OF SELECTED POLISH DAM RESERVOIRS

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Summary. Dam reservoirs contribute significantly to global gross methane emission which has been estimated at 104 ±7.2 Tg CH_4 per year. However, this value might be far from real since the contribution of small dam reservoirs has not been taken into consideration. This study was aimed at estimating the amount of methane emitted from selected lowland dam reservoirs in Poland in relation to hydrochemical conditions: depth, organic matter content, red-ox, pH. The research was conducted on 4 dam reservoirs located in a SW to NE cross-section of Poland: Turawa, Sulejowski, Włocławski, Siemianówka. The reservoirs show a wide range of average amount of collected gas and CH_4 content. Calculated methane ebullition amounted to 4 mg $m^{-2}d^{-1}$ in Sulejowski, 401 mg $m^{-2}d^{-1}$ in Siemianówka, 42 mg $m^{-2}d^{-1}$ Turawa and 413 mg $m^{-2}d^{-1}$ in Włocławski reservoirs. The most spatially diversified results were reported for Włocławski and the most stable for Siemianówka and Sulejowski. The remarkably high values of methane emission noted for Siemianówka and Włocławski reservoirs exhibit the range typical to tropical reservoirs, which suggest potential for CH_4 exploitation for energy production purposes.

Key words: methane, sediments, dam reservoirs

INTRODUCTION

Methane is considered to be one of the most active greenhouse gases, whose concentration increase in the atmosphere is currently about twenty times faster than that of other greenhouse gases of global importance [IPCC 2001]. It was estimated that approximately 45% of methane in the atmosphere comes from areas periodically or permanently flooded with water, such as rice fields, marshes, lakes.

Dam reservoirs are also considered to be significant sources of methane emissions, responsible for about 18% of global greenhouse effect of anthropogenic origin. Globally, methane emissions from dam reservoirs are estimated at

104 ±7.2 Tg CH_4 per year. It was estimated that the average methane emission form dam reservoirs of the temperate zone is 55.1 ±84.7 mg m^{-2} day^{-1}, and from the tropical zone – about 136 ±245 mg m^{-2} day^{-1} [Sournis *et al*. 2005, Lima *et al*. 2008]. However, these numbers, as calculated on the basis of the case of large dam reservoirs (mainly Brasilian, Indian, Canadian), may be inaccurate since they exclude a great number of small water bodies [ICOLD 2003, Sournis *et al*. 2005].

Therefore, the aim of this study was to estimate the amount of CH_4 emitted from sediments of selected Polish dam reservoirs and to indicate its potential relationship with depth, organic matter content and other environmental factors.

METHODS

The research was conducted on 4 dam reservoirs: Turawa, Sulejowski, Wloclawski and Siemianowka, characterised by a wide range of hydrological and

Table 1. Selected morphometric and hydrochemical parameters charactering the conditions in studied dam reservoirs [Ambrożewski 1996, Gurwin *et al*. 2005, Górniak and Jekatierynczuk-Rudczyk 2006, Suchowolec 2006, Gierszewski *et al.* 2006]

Parameters	Turawa Reservoir	Sulejowski Reservoir	Włocławski Reservoir	Siemianówka Reservoir
River	Mala Panew	Pilica	Vistula	Narew
Length of reservoir, km	7	17	58	11
Mean depth, m	4	3,5	5,5	2,5
Volume, km^3	106	75	408	62
Mean water retention time, days	110	42	5	540**
Mean organic matter content in sediments, %*	6,5 ±9,9	6,5 ±4,7	11,5 ±7,7	10,7 ±3,4
Mean carbonates content in sediments, %*	< 1	12 ±8,5	22 ±8,6	< 1
Mean content of CH_4 in pore gas, %*	9 ±14	4 ±7	27 ±23	49 ±15
Mean ebulition of methane, mg m^{-2} day^{-1}*	42 ±98	4 ±10	413 ±587	401 ±618
Additional information on environmental problems	heavy metals, eutrophication	eutrophiction	hydrocarbons	Humic substances

*data collected for this research, ** estimated from water exchange time

and hydrochemical conditions (Tab. 1). Gas and sediment samples were collected from the reservoirs in several points randomly distributed over the bed of each reservoir. Pore gas was collected using traps set at the bottom of the reservoirs for several hours. Bottom sediments were collected at the same stations using an Ekman-Birge sampler. The quantity of collected gas and temperature (digital thermometer, ±0.1°C), pH (WTW SenTix SP, ±0.01), redox (ORP SenTix WTW, platinum, ±0.01 mV) of sediments were measured during sampling.

Analyses of the concentration of CH4 in pore gas samples were made using an ELWRO 504 gas chromatograph. Analyses of water content and organic matter content were made using the gravimetric method [Håkanson and Jansson 1983]. The content of carbonates in the sediments was analysed using a calcite bomb.

RESULTS

The studied reservoirs showed wide variations in the amount of pore gas emitted from the sediments. The lowest amount of gas was collected from the Sulejowski Reservoir (38 ml $m^{-2}d^{-1}$ in average), where at several stations no gas has been detected at all. The highest gas amounts were collected in the Włocławski Reservoir: 3114 ml $m^{-2}d^{-1}$, on average. In other studied reservoirs mean gas emission was calculated at 990 ml $m^{-2}d^{-1}$ in Siemianowka and 1445 ml $m^{-2}d^{-1}$ in Turawa. The largest spatial variation in the amount of gas emitted from the sediment and in methane percentage content was recorded in the Włocławski Reservoir, while the smallest in the Sulejowski (Fig. 1, Tab. 1). Percentage con-

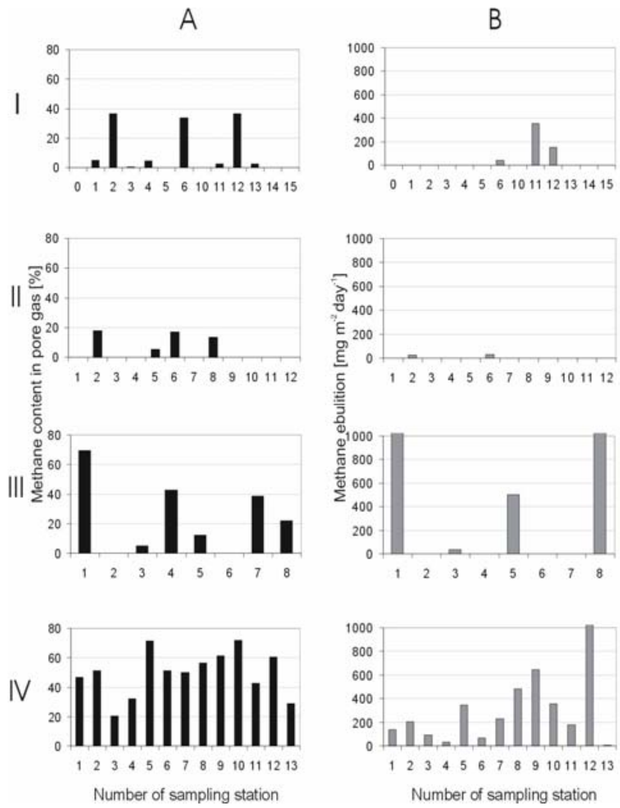

Fig. 1. Methane percentage content in pore gas (A) and methane ebullition from sediments (B) of dam reservoirs: Turawa (I), Sulejowski (II), Włocławski (III), Siemianówka (IV)

tent of methane in pore gas was the lowest in the Sulejów Reservoir, where it reached only 4.5% on average and did not exceed 20% at either station. The highest content of methane was recorded in gas samples collected from the Siemianówka Reservoir (49% on average). In other reservoirs lower values were noted – 27% in Włocławski Reservoir and 9% in Turawa.

Taking into account the average percentage content of methane, calculated values of methane ebullition amounted to 4 mg $m^{-2}d^{-1}$ in the Sulejowski reservoir, 401 mg $m^{-2}d^{-1}$ in Siemianówka, 42 mg $m^{-2}d^{-1}$ in Turawa and 413 mg $m^{-2}d^{-1}$ in Włocławski (Tab. 1, Fig. 1).

DISCUSSION

Jones *et al*. [1982] indicated factors that regulate the rate of CH_4 emission from sediments under natural conditions: the availability of substrates, temperature, redox potential, pH, water column. The highest ebullition rate was recorded in the Włocławski and Siemianówka Reservoirs, which are rich in organic matter, however only in the Włocławski Reservoir this relationship was confirmed with a weak correlation coefficient ($r = 0.42$, $p = 0.11$). Although, some trends of increased ebullition were noted in areas of organic matter accumulation. Extremely low methane ebullition in the Sulejowski Reservoir may be due to toxic effects of cyanobacterial blooms or abundant sulphates and nitrates which, according to Conrad *et al*. [1999], may inhibit methanogenesis and increase denitrification simultaneously [Trojanowska and Kurasiewicz 2009]. However, at the same time, methane emission showed a significant relationship with pH ($r = 0.70$, $p = 0.016$).

Heavy metals, abundant in sediments of the Turawa Reservoir [Gurwin *et al*. 2005], are probably responsible for inhibition of methanogenesis, according to Mishra *et al*. [1999]. The ebullition of CH_4 from the reservoirs Sulejowski and Turawa displays lower values characteristic for temperate water bodies (Tab. 1). The surprisingly high values of methane emitted from sediments of the Wloclawski and Siemianowka reservoirs are comparable with results recorded in large tropical reservoirs [Sournis *et al*. 2005, Santos *et al*. 2006]. The results presented in this paper are derived solely from the summer sampling, the most intense period of processing of organic matter in sediments, which could cause overestimation of CH_4 emission.

All studied reservoirs are shallow and rather rich in organic matter (Tab. 1). An increase of percentage contribution of CH_4 with depth was noted for the Turawa and Siemianówka reservoirs ($r = 0.42$, $p = 0.11$, and $r = 0.74$, $p = 0.004$, respectively). It was previously confirmed by Joyce and Jewell [2003], who proved that the highest potential of methane ebullition is exhibited by shallow waters, and the highest rate of the process in noted up to 5 m depth, while at greater depths is significantly decreased. Furthermore, Lima [2005], on the basis of the isotopic composition of carbon in methane, confirmed that with increasing depth in large dam reservoirs the rate of CH_4 consumption significantly increases, which in consequence reduces its emissions. Weaving and currents impact on sediments greatly accelerates and intensifies ebullition of methane from sediments in dam reservoirs [Keller and Stallard 1994, Joyce and Jewell 2003], hence probably the increased liberation of methane from sediments in the rheolimnetic Włocławski Reservoir and in other reservoirs at stations located close to the main stream course (Fig. 1).

CONCLUSION

High values of methane emission recorded in the Włocławski and Siemianówka reservoirs suggest that the contribution of lowland shallow waters may be relatively significant in the total greenhouse gas budget. The technology of methane recovery from sediments and water of dam reservoirs allows using pore gas for energy production purposes, global reserves of pore gas being estimated at 100 ±6.9 Tg CH_4 per year [Kilkuchi and Maral 2007, Lima *et al*. 2008]. In this case temperate lowland shallow dam reservoirs should be also taken into consideration.

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Acknowledgements. The studies were supported by the Polish Ministry of Higher Education and Science, grant No R1205602. We would like to acknowledge Janusz Krajniak and Radoslaw Drynda for their support in field works.

EMISJA METANU Z OSADÓW WYBRANYCH ZBIORNIKÓW ZAPOROWYCH W POLSCE

Streszczenie. Udział zbiorników zaporowych w globalnej emisji metanu ocenia się jako znaczący, oszacowano go na 104 ±7,2 CH_4 Tg rocznie. Jednak szacunki te mogą odbiegać od rzeczywistości, ponieważ nie uwzględniają emisji z małych zbiorników zaporowych. Celem badań było oszacowanie wielkości emisji metanu z wybranych nizinnych zbiorników zaporowych w Polsce w odniesieniu do warunków hydrochemicznych i morfometrycznych: głębokości, zawartości materii organicznej, redox, pH. Badania przeprowadzono w 4 zbiornikach zlokalizowanych w transekcie z południowego zachodu na północny wschód Polski: Turawie, Sulejowskim, Włocławskim, Siemianówce. Ilość gazu wydzielanego z osadów i % zawartość w nim CH_4 były znacznie zróżnicowane w badanych zbiornikach. Wyliczona ebulicja metanu osiągnęła wartości: 4 mg $m^{-2} \cdot d^{-1}$ w Sulejowskim, 401 mg $m^{-2} \cdot d^{-1}$ w Siemianówce, 42 mg $m^{-2} \cdot d^{-1}$ w Turawie i 413 mg $m^{-2} \cdot d^{-1}$ we Włocławskim. Najbardziej zróżnicowane przestrzennie wyniki zanotowano w zbiorniku Włocławskim, natomiast najbardziej wyrównane w Siemianówce. Wyjątkowo wysokie wartości emisji metanu ze zbiorników Siemianówka i Włocławskiego przekraczały wartości uważane za typowe dla zbiorników tropikalnych, co wskazuje na możliwość pozyskiwania metanu z tego źródła do celów energetycznych.

Słowa kluczowe: metan, osady, zbiorniki zaporowe