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POLLUTANT LOADS FROM ELECTRIC POWER PLANTS TO THE HAVANA BAY

The assessment of pollutant loads from the electric power plants "Otto Parellada", "Antonio Maceo" and "Frank País", employing sea water for cooling purposes and fuel-oil as energy source, is a part of the Principal State Problem "Decontamination of the Havana Bay" belonging to the Science and Technology National Plan. This investigation is being supported by the United Nations Agencies UNDP, UNEP and UNESCO and by national institutions under CUB/80/001 Project.

Effluents from water treatment, air heater cleaning, boiler cleaning and blowdown as well as cooling water at inlet and outlet were analysed. In each case large quantities of pollutants (such as acids, alkalies and metals) were found but no rise in amount of dissolved oxygen was observed. Buffer capacity of cooling water has appeared substantial and it may be used to neutralize some discharges.

1. INTRODUCTION

One of the research tasks belonging to the Principal State Problem "Decontamination of the Havana Bay" of the Science and Technology National Plan is to characterize wastewaters from the electric power plants "Otto Parellada", "Antonio Maceo" and "Frank País", located in the surroundings of the Havana Bay. These investigations are supported by the United Nations Agencis UNDP, UNEP ans UNESCO and by various national institutions under CUB/80/001 Project.

Sea water is commonly used for cooling purposes in our country. Although it is considered to be a cheap alternative for heat exchange, it affects, however,

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Table 1

Main characteristics of the electric power plants

Podstawowe charakterystyki elektrowni

Characteristics	"Otto Parellada"	"Antonio Maceo"	"Frank País"
Units	2	4	2
Capacity (MW)	124	194	40
Boiler pressure (at)	63 and 96	63 and 96	63
Cooling water inlets	1	1	1
Cooling water outlets	1	3	1
Water treatment system	a(1)	a(1)	b(2)
Cooling water flow (maximum capacity m^3/h)	31,000	58,600	9,000

(1) Anionic and cationic exchangers and mixed-beds.
(2) Anionic and cationic exchangers.

the marine environment [12]. In these power plants, cooling water is mixed on its way back to the bay with wastewater resulting from different operations performed, but only in "Antonio Maceo" and "Frank País" plants the effluents from water treatment plants are discharged separately into the bay.

The main characteristics of these thermal electric power plants are shown in tab. 1. In all the cases fuel oil is employed. The municipal wastes and other ones coming from minor cleaning operations flow towards the local sewage.

In this paper the measurements of different physicochemical characteristics are discussed. The pollutant loads flowing to the Havana Bay are estimated and their environmental impact is evaluated. Some measures to decrease its negative effect are proposed.

2. PROCEDURE

The investigations included the analyses of the effluent from the water treatment, heater cleaning, chemical cleaning of boilers, boiler blowdown, as well as the assessment of cooling water quality at the inlet and outlet points. The parameters determined in each operation, sampling frequency and the employed analytical technique are given in tab. 2. The measured parameters of effluents were chosen according to RICE and STRAUSS [9]. For comparative reasons hydrocarbon, total and faecal coliforms, temperature and dissolved oxygen were determined in cooling water at the inlet and outlet points. Works from UNESCO [12], O'KANE [8] and Federal Power Commission [5] were taken into account when preforming these analyses.

In order to take advantage of the buffer capacity of sea water used for cooling [6], and by this means to neutralize alkali and acid discharges, curves

Table 2

Parameters determined and sampling frequency

Oznaczone parametry i częstość pobierania prób

Operation	Parameters	Frequency
Water treatment:		
Cationic exchange	$[H_2SO_4]^{(e)}$, pH[a], metals[b], total and suspended soilds[a]	10 min
Anionic exchange	$[NaOH]^{(e)}$, pH[a]	10 min
Air heater cleaning	pH[a], metals[b], total and suspended solids[a]	10 min
Boiler cleaning	$[HCl]^{(e)}$, $[N_2H_4]^{(e)}$, $[NO_2]^{(e)}$, $Fe^{(e)}$, $Cu^{(e)}$	
Boiler blowdown	COD[a], pH[a], temperature, total P[a], total and suspended solids[a]	8 h
Cooling water	pH[c], temperature, hydrocarbon[d], total P[c], dissolved O_2[c], coliforms[a]	1 h

[a] *Standard Methods* [2].
[b] Atomic spectroscopy.
[c] Strickland–Parsons [3].
[d] Infrared spectroscopy.
[e] Reference [4].

of pH versus different amounts of H_2SO_4, HCl and NaOH added to sea water were determined. These curves were used to predict pH variations in cooling waters due to alkali and acid discharges from different operations. In order to verify the validity of this method, pH values in cooling water mixed with the effluents from water treatment station at "Otto Parallada" plant were compared with the corresponding data given in the curves.

The data obtained at the inlet and outlet of the cooling water were analyzed to find out whether the differences were statistically significant ($\alpha = 0.05$). Student's "t" test was used for larger groups and the non-parametric Wilcoxon–Man–Widney test for the smaller ones [2].

Selected discharges limits are cited by RICE and STRAUSS [9] and MINSAP [7].

3. RESULTS AND DISCUSSION

3.1. WATER TREATMENT

The characteristics of effluents from water treatment stations at the three electric plants are summarized in tab. 3. These effluents show high acidity and alkalinity. As far as metals are concerned, it has been found that only iron concentrations were slightly higher than 1 mg/dm^3, as an average.

Table 3

Results of the tests in the water treatment plant during the regeneration of ion-exchange resins

Wyniki pomiarów w zakładzie oczyszczania wody podczas regeneracji jonowymieniacza

Type of exchanger	"Otto Parellada" Maximum	"Otto Parellada" Average	"Antonio Maceo" Maximum	"Antonio Maceo" Average	"Frank País" Maximum	"Frank País" Average
Cationic exchanger:						
H_2SO_4 (g/dm^3)	59.0	8.8	49.0	12.8	40.0	16.0
Total solids (mg/dm^3)	32.3	9.8	41.0	9.4	10.0	9.5
Suspended solids (mg/dm^3)	20.3	2.9	13.0	4.0	8.0	2.0
Iron (mg/dm^3)	—	1.7	—	1.3	—	2.1
Copper (mg/dm^3)	—	0.06	—	0.09	—	< 0.01
Zinc (mg/dm^3)	—	< 0.01	—	0.01	—	< 0.01
pH	0.2 minimum	0.80	0.3 minimum	0.72	0.30 minimum	0.60
Anionic exchanger:						
NaOH (g/dm^3)	38.0	13.0	38.4	11.8	34.0	13.8
pH	14.0	13.8	14.0	13.0	14.0	13.8

Table 4 shows pH extreme values measured at "Otto Parellada's" outlet of cooling water and those that might occur in cooling waters from "Antonio Maceo" and "Frank País" if the water treatment effluents were discharged into them. As we can see, even at the minimum water flow and the maximum pollutant load of the effluent, the extreme pH values are within the permissible limits.

Table 4

Extreme values of pH at the outlet of cooling water during regeneration of water in a treatment plant

Ekstrementalne wartości pH przy wylocie wody ochładzanej podczas regeneracji

Different types of regeneration	Extreme values of pH		
	"Otto Parellada"[a]	"Antonio Maceo"[b]	"Frank País"[b]
Cation regeneration	6.29	6.84	7.07
Anion regeneratin	8.27	8.38	8.35

[a] Results of measurements.
[b] Values determined from curves obtained at the laboratory.

3.2. AIR HEATER CLEANING

Spectrographic analysis showed the presence of Co, Fe, Cr, Pb, Mn, Ni V, Cu, Sb, Al, Sn, Bi and Mo in wastes from air heater cleaning. The first eight elements plus Cd and Zn were determined quantitatively. The results are given in tab. 5.

Table 5

Minimum and maximum metal concentrations in the wastes from the air heaters cleaning

Minimalne i maksymalne stężenia metali w ściekach pochodzących z czyszczenia podgrzewaczy powietrza

Metals	Dissolved metals mg/dm³	Suspended metals μg/g Fe, Ni and V in %	Total metals mg/dm³
Fe	5.0–4330	0.28–26.03	63–5835
Ni	0.38–354	0.02–1.18	1.2–412
V	< 1.0–1120	0.04–3.92	< 1.0–1485
Mn	< 0.10–34.8	11.7–1560	1.5–41.3
Co	< 0.10–4.7	< 3.7–293	0.41–5.9
Cu	< 0.10–10.6	5.8–940	< 0.10–13.1
Pb	< 0.5	< 2.0–338	< 0.5–4.5
Cr	< 0.10–4.8	< 3.5–394	0.12–6.8
Zn	0.10–8.8	< 2.4–325	< 0.10–10.2
Cd	< 0.02–0.07	< 0.4–5.2	< 0.02–0.07

In most cases the pollutant loads from air heater cleaning exceed the established maximum tolerances of the water body [10], [7] due to the frequency of this operation (more than once a month at "Frank País" and once every 3–6 months at the remaining plants) and the high metal contents of the wastes.

3.3. BOILER BLOWDOWN

These wastes are characterized by high pH and temperature. Total phosphorus was found to be less than 5 mg/dm³. Metals and solid concentrations are given in tab. 6.

3.4. CHEMICAL BOILER CLEANING

The results given in tab. 7 indicate the presence of high concentrations of acid and metals in this waste. N_2H_4 used as a passivator may substantially reduce the oxygen content of the receiving water body and the NO_2^- presence signifies a considerable nutrient source.

Table 6

Characteristics of boilers blowdown discharged into the bay

Charakterystyka spalin zrzucanych do zatoki

Characteristics	"Otto Parellada"		"Antonio Maceo"	
	Maximum	Average	Maximum	Average
pH	10.5	9.5	11.2	10.0
COD (mg/dm^3)	49.4	19.8	46.3	25.9
Total phosphorous (mg/dm^3)	1.92	0.9	3.2	1.9
Total solids (mg/dm^3)	44.0	17.0	159.0	60.0
Suspended solids (mg/dm^3)	23.0	9.0	28.0	12.0
Fe ($\mu g/dm^3$)	< 2.0	< 2.0	< 2.0	< 2.0
Cu ($\mu g/dm^3$)	< 2.0	< 2.0	< 2.0	< 2.0
Temperature (° C)	105	100	103	100

In "Frank País" plant boiler blowdown is employed for air heaters cleaning.

Table 7

Characteristics of wastes from boilers cleaning

Charakterystyka zanieczyszczeń pochodzących z czyszczenia kotłów

Characteristics	Maximum g/dm^3	Average g/dm^3
HCl	60	30
Fe	10	7
Cu	0.6	0.3
N_2H_4	0.3	0.25
NO_2^-	10	5.5

Extreme pH values determined in cooling water and resulting from boiler cleaning wastes discharged from the "Otto Parellada", "Antonio Maceo" and "Frank País" plants were 3.2, 1.5 and 2.2, respectively.

3.5. COOLING WATER

Comparison of the results of the analyses of cooling water at the inlet and outlet points of each electric power plant indicated the significant statistical differences of temperature in all the plants and of dissolved oxygen concentration in "Otto Parellada" and in the channels 1 and 3 of "Antonio Maceo". According to the Student "t" test used, the differences in pH and hydrocarbons were not significant. The remaining parameters (total phosphorous and

coliforms), according to the Wilcoxon–Man–Widney test, did not show significant differences in any plant.

The unexpected high concentrations of dissolved oxygen in cooling water observed in "Otto Parellada" at the discharge point (tab. 8) may be attributed to the turbulence of the water flowing through the plant. The resulting increase of dissolved oxygen exceeds its losses occurring at elevated temperatures.

Table 8

Dissolved oxygen (DO) (mg/dm^3) and temperature (°C) in cooling waters

Rozpuszczony tlen (mg/dm^3) i temperatura (°C) chłodzonej wody

Plant	DO surface			DO bottom		Temperature	
	n[1]	X[2]	SD[3]	X[2]	SD[3]	X[2]	SD[2]
"Otto Parellada"							
inlet	64	1.68	0.38	1.59	0.37	27.8	0.80
outlet	64	2.04	0.37	2.00	0.45	34.7	1.60
"Antonio Maceo"							
inlet	79	2.30	0.50	2.28	0.53	28.5	0.60
outlet 1	79	2.43	0.51	2.48	0.49	31.8	1.20
outlet 2	49	2.29	0.53	2.27	0.48	32.8	1.70
"Frank País"							
inlet	30	1.54	0.54	1.57	0.61	27.4	0.50
outlet	30	1.58	0.56	1.50	0.47	32.7	2.10

[1] Number of measurements.
[2] Mean value.
[3] Standard deviation.

Table 9

Pollutant loads released into the bay from water treatment and boiler blowdown

Ładunki zanieczyszczeń spuszczanych do zatoki pochodzące z obróbki wody i spalin

Pollutants	"Otto Parellada"	"Antonio Maceo"	"Frank País"
H_2SO_4 (kg/day)	628	789	48
NaOH (kg/day)	103	165	33
Total solids (kg/day)	704	586	28
Suspended solids (kg/day)	210	247	6
Total P (kg/day)	0.86	2.8	—
Fe (g/day)	121	80	6.3
Cu (g/day)	4	6	< 0.03
Zn (g/day)	< 0.7	0.6	< 0.15

In the remaining plants, however, the variation of this parameter is not considerable.

The highest temperature difference between outlet and inlet was recorded in "Otto Parellada" (6.9° C), being followed by "Frank País" (5.3° C) and "Antonio Maceo" (3.3° C and 4.3° C) plants.

3.6. POLLUTANT LOADS FLOWING INTO THE BAY

The daily average loads from water treatment and boiler blowdown are shown in tab. 9. Pollutant loads from heater cleaning are shown in tab. 10, and those from the boiler cleaning — in tab. 11. The latter operation is performed every 4–5 yaers.

Table 10

Metals from each cleaning of air heater

Metale z każdego czyszczenia podgrzewaczy powietrza

Metals	"Otto Parellada"	"Antonio Maceo"	"Frank Pais"
Fe (kg)	692.5	70.22	29.9
Ni (kg)	33.09	4.22	0.58
V (kg)	111.4	4.36	1.81
Mn (kg)	7.78	0.92	0.28
Co (g)	565	20.7	17.1
Cu (g)	1584	93.7	24.8
Pb (g)	490	8.0	0.73
Cr (g)	651	26.9	13.0
Zn (g)	917	31.3	8.5
Cd (g)	6.3	0.61	0.11

Table 11

Pollutant loads released into the bay from boilers cleaning (kg)

Ładunki zanieczyszczeń spuszczanych do zatoki a pochodzących z czyszczenia kotłów

Pollutants	"Otto Parellada"		"Antonio Maceo"		"Frank País"
	Maximum	Minimum	Maximum	Minimum	
HCl	3600	1800	4650	1800	1140
Fe	840	420	1085	420	266
Cu	36	18	46	18	11
N_2H_4	30	15	39	15	9
NO_2^-	660	330	852	330	209

3.7. USE OF POLLUTED WATERS OF THE HAVANA BAY BY ELECTRIC POWER PLANTS

The effect of the use of polluted Havana Bay waters on the operation of the plants may be estimated from tab. 12. The cleaning frequency of condensers in two of these plants are compared with that in "Máximo Gómez" (Mariel, Havana province) in which non-polluted sea water is used for cooling purposes [3].

Table 12

Frequency of condensers cleaning at the electric plants "Otto Parellada", "Antonio Maceo" and "Máximo Gómez"

Częstość czyszczenia chłodnic w elektrowniach "Otto Parellada", "Antonio Maceo" i "Máximo Gómez"

Plants	Cleaning of condensers times/month	Salinity of cooling water ‰
"Máximo Gómez"	1	35.46
"Otto Parellada"	5–6	34.26
"Antonio Maceo"	4–5	34.68

4. CONCLUSIONS

1. Discharge of the effluents from "Otto Parellada" water treatment plant into the cooling water outlet has no significant effect on pH value. Therefore, mixing the effluents with cooling water is suggested for the remaining plants.

2. Air heater and boiler cleaning is an important source of pollution, therefore conventional treatment for "Frank País" plant is recommended. These studies should be continued to solve this problem in the remaining plants where this treatment cannot be applied because of the space limitations. Methods of some metals recovery should also be developed.

3. The use of boiler blowdown for heater cleaning is recommended for "Otto Parellada" and "Antonio Maceo" plants. If it cannot be done, the so far applied method should be used.

4. Thermal pollution is the main effect of cooling waters being discharged into the bay. Studies are being made at present to find solutions for this problem.

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ZANIECZYSZCZENIE ZATOKI HAWAŃSKIEJ ŚCIEKAMI Z ELEKTROWNI

Ocena ładunku zanieczyszczeń pochodzących z elektrowni „Otto Parellada", „Antonio Maceo" i „Frank País", stosujących wodę morską do chłodzenia i olej opałowy jako paliwo, jest częścią Problemu Rządowego „Odkażanie Zatoki Hawańskiej", należącego do Narodowego Planu Nauki i Techniki. Badania te finansowane są przez następujące agencje ONZ: UNDP, UNEP i UNESCO oraz przez instytucje rządowe w ramach projektu CUB/80/ /001.

Badano zanieczyszczenia pochodzące z obróbki wody, z czyszczenia podgrzewaczy powietrza i kotłów, z wypływu spalin oraz zanieczyszczenia wody chłodzącej na wlocie i jej odprowadzeniu. Każde z tych źródeł wprowadza duże ilości zanieczyszczeń, takich jak: kwasy, zasady i metale, ale nie powoduje wzrostu zawartości rozpuszczonego tlenu. Pojemność buforowa wody chłodzącej jest znaczna i może być wykorzystana przy unieszkodliwianiu pewnych ładunków zanieczyszczeń.

DIE VERSCHMUTZUNG DER BUCHT VON HAVANNA DURCH ELEKTRIZITÄTSWERKE

Die Bewertung der Schmutzfracht aus den Elektrizitätswerken Otto Parellada, Antonio Maceo und Frank País, welche das Meerwasser für Kühlzwecke und Heizöl als Brennstoff verwenden, ist ein Teil des Regierungsproblems "Dekontaminierung der Bucht von Havanna", welches zum Staatsplan für Wissenschaft und Technik gehört. Die Untersuchungen werden durch die UN-Organisationen wie UNDP, UNEP und UNESCO, sowie durch die Regierung im Project CUB/80/001 gefördert.

Untersucht wurden die Schmutzfrachten aus der Wasseraufbereitung, Reinigung der Luftvorwärmer und der Kessel, der Emission der Abgase sowie in entnommenem und wieder abgeleitetem Kühlwasser. Durch jede der genannten Quellen werden beträchtliche Schmutzfrachten von Säuren, Basen und Metallen emitiert – jedoch ohne wesentlichen Einfluß auf den Sauerstoffgehalt. Die Pufferkapazität des Kühlwassers ist beträchtlich und kann bei gewissen Schmutzarten ausgenutzt werden.

ЗАГРЯЗНЕНИЕ ГАВАНСКОГО ЗАЛИВА ОТ ЭЛЕКТРОСТАНЦИЙ

Оценка количества загрязнений от электростанций „Отто Пареллада", „Антонио Мацео" и „Франк Пэс", применяющих морскую воду для охлаждения и гарное масло в качестве топлива, является частью Правительственной проблемы „Очистки Гаванского залива", входящей в состав Национального плана науки и техники. Эти исследования финансируются следующими агентствами ООН: ЮНДП (Программа Развития ООН), ЮНЕП и ЮНЕСКО, а также правительственными организациями в рамках проекта КУБ/80/001.

Исследовано загрязнение от обработки воды, очистки воздухоподогревателей и очистки котлов, от влияния выхлопных газов, а также загрязнения охлаждающей воды на входе и её отводе. Каждый из этих источников вводит большие количества загрязнений, таких как кислоты, щёлочи и металлы, но не вызывает увеличения содержания растворённого кислорода. Буферная ёмкость охлаждающей воды является значительной и может быть использована при обезвреживании некоторых количеств загрязнений.