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Statistical analysis for the assessment of water treatment parameters by three macrophytes identified

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Abstract

The lagooning floating process is an extensive treatment of wastewater. The study conducted on the campus of Abomey for phytopurification had the ambition to estimate models of evolution of the monitoring parameters: temperature, electrical conductivity, redox potential, hydrogen potential, dissolved oxygen, turbidity, after introduction of floating species *Eichhornia crassipes Mart. Solms-Laub.* (Water hyacinth), *Pistia stratiotes L.* (Water lettuce) and *Lemna minor L.* (Duckweed) in domestic effluents. After sampling day, the monitoring parameters of the operation were measured in accordance with European standards and AFNOR. The models estimated in Stata 11 were generally significant ($p < 0.05$) and showed that the three floating macrophytes induce physico-chemical reactions in their respective areas by impacting the elevation of part of the EH, the dissolved oxygen and on the other hand, the decrease in electrical conductivity and turbidity. Hyacinth was varied from 4.39 mV EH and average electrical conductivity of water an average of 13.85. These results were predictive performance of certain purification plants, but primarily of water hyacinth with efficiencies of COD and BOD5 and TKN by 70%, 52.8%, 78.3%, followed by lettuce ' water that contributes to the elimination of nitrate nitrogen with an allowance of 27% and finally the duckweed. This study allows to optimally exploit the potential of scavenging agents mentioned, offering several channels of mixed floating macrophyte lagoons.

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Introduction

Management of domestic waste water remains a problem in Benin. The measures put in place in major cities like Cotonou, Abomey-Calavi boil down to simple evacuation and transport of excreta sanitation works independent to the only station in Ekpè SIBEAU purification which yields no longer meet the standards in the countries (GBAGUIDI, 2003). This situation leaves the margin of Benin in environmental technologies developed for the treatment after sewage, which are now popular in the Developing country (PED) of West Africa, especially those adjacent to it. For this purpose, it is appropriate to conduct extensive research on a process incorporating the present context, is the lagooning floating. This is an extensive system, economic and environmentally friendly (Kengne Noumsi, 2000; Brouillet et al., 2007, Aina et al., 2009). It builds self-purifying capacity of natural ecosystems where there is a symbiotic activity between aquatic plants and microorganisms living either free or fixed (Colin, 2009). The use of aquatic macrophytes for treating waste water is gaining attention as a promising method to reduce pollutant levels in water bodies, municipal sewage and industrial effluent; the plants utilize the nutrients and other soluble compounds present in the water, supporting a habitat for numerous organisms (Moreno-Grau et al., 1996). Additionally, other abilities such as the assimilation of heavy metals make aquatic macrophyte purification systems more attractive (Keskinkan et al., 2003; Mishima et al., 2006). To evaluate its performance and effectiveness, several global parameters of sewage pollution are measured and monitored on a continuous or discontinuous.

Conventionally, special importance is given to so-called purification performance parameters: COD, BOD_5, NTK, $N-NO_3^-$, $N-NO_2^-$, $N-NH_4^+$, $P-PO_4^{3-}$, fecal coliforms and streptococci represent the pollution load of wastewater (Aina et al., 2012). Determination system and their evolution in the reactor, provide information on treatment efficacy. Rejsek (2002) and Echihabi et al., 2000 describe the temperature, pH, E_H, turbidity, dissolved oxygen, the electrical conductivity of monitoring parameters of the operation of a processing system. For example, the study of Wang et al. (2008) shows the importance of turbidity to assess the performance of floating macrophytes, namely water hyacinth, water peanuts, duckweed, other aquatic plants purifying in the improvement of the water transparency (MCM system) for experimental sites of lake Taihu. In fact, these parameters give an appreciation of the mechanism established under tending the various physico-chemical reactions. Thus, monitoring the operation shows the performance of the process. More advantageously, making a contribution to statistical analysis tool in assessing the effects of purification plant resources to use, far from being free, open new avenues of investigation.

This study is therefore part of this outlook and the overall purpose of a statistical model for the treatment of domestic sewage with *Eichhornia crassipes Mart. Solms-Laub.* (Water hyacinth), *Pistia stratiotes L.* (Water lettuce) and *Lemna minor L.* (Duckweed). She has specifically: i) characterize domestic wastewater at the entrance of a mini STEP ii) evaluate the intrinsic values of three species floating in the treatment of domestic sewage by evolution models parameters monitoring the operation, iii) determine the yield purification performance parameters.

Materials and methods

Study area

The mini station lagooning floating was installed on the Technology Center for Practical Water Supply and Sanitation (CTPEA) Laboratory of Science and Technology of Water (LSTE) of the Ecole Polytechnique of Abomey-Calavi in University of Abomey-Calavi (Figure 2). Located in the town of Abomey in Benin (Figure 1), the campus is characterized by a climate of Guinean type with two wet seasons and two dry seasons (Adam and Boko, 1983). The average annual rainfall is around 1200 mm. The average monthly temperature ranged from

27 ° C and 31 ° C with a deviation of ± 3.2 °C between the warmest month (March) and the cooler (August). The relative humidity was 76.84% (January) to 84.55% (July) (Akouedegni, 2011).

Materials and methods

Upstream of the different activities, there was the design and construction of the experimental set up on the CTPEA, which was a mini system of four pools:

i) an anaerobic lagoon, leading the system whose primary role was to partially digest the pollutants contained in domestic sewage;

ii) three sub-basins in floating macrophytes in parallel connected to the anaerobic tank by pipes made of PVC (Polyvinylchloride). In this case, the principle and operation of the lagoons were based on the action of plants and symbiotic micro-organisms in removing pollutants.

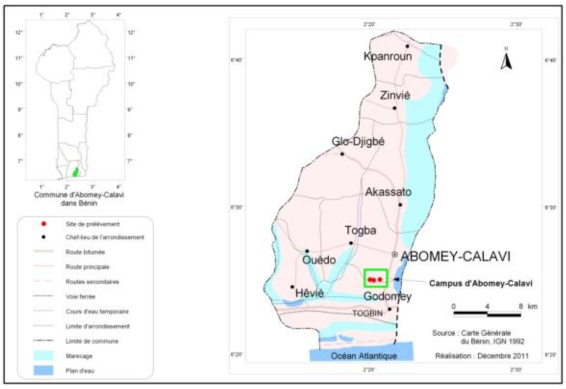

Fig. 1. Location of CUAC in Benin and in the town of Abomey.

Fig. 2. Mini station lagooning floating.

Three days after pumping of domestic wastewater from a septic tank and halls, the pretreated wastewater in the anaerobic pond flowed steadily after opening the valves in the secondary lagoons. The plants were introduced after 5 days and their contact time with the effluent was 10 d. Continuous measurement (daily) global parameters was carried out but for the purification performance parameters, monitoring was periodic. All analyzes were made according to the AFNOR standards and European standards (Table 1). The characterization of wastewater initially helped define a limit in salinity tolerable by plants.

A descriptive analysis by representations in boxes of mustaches parameters monitoring the operation was summarily informed of the variations observed around the central values of these variables. It was conducted using the software R.

To analyze the effects of duckweed, water lettuce and water hyacinth on the evolution of each physicochemical parameter and to compare the efficiency level of each plant, models were estimated in Stata 11. Evolution models of monitoring parameters of the operation are established via analysis of variance based on linear regressions. Each model estimated a quantitative variable corresponded to explain (a physicochemical parameter) and two main qualitative variables "period" and "plant", which have been created. The variable "plant" is a categorical variable, the terms representing the three plants tested (1- duckweed, water lettuce 2-and 3-water hyacinth) on the variable "period", c is a binary variable taking the value (0) if the sample parameter was made before the introduction of the plant and in the basin (1), if it is after its introduction in the basin. The model is as follows:

$$Y = \alpha + \beta_1 x_1 + {}^1\beta_2 {}^1x_2 + {}^2\beta_2 {}^2x_2 + {}^1\beta_3 (x_1 * {}^1x_2) + {}^2\beta_3 (x_1 * {}^2x_2) + \varepsilon \quad (7)$$, with:

Y: quantitative variable to be explained, means the values of the parameter of interest is;

x_1 : means the period, binary variable coded as 0 if the sample of studied parameter was made before the introduction of the plant in the basin and whether the levy of a parameter was made after the introduction of the plant in the basin;

$^{1}x_{2}$ et $^{2}x_{2}$: categorical variables (dummies) . $^{1}x_2$ taking the value 0 if the plant was duckweed and 1 if it was water lettuce; $^{2}x_2$ took the value 0 if the plant was duckweed and 1 if it was water hyacinth. Duckweed has been used here as reference plant. The specific choice of a reference plant had little importance. Only the sense of comparison when interpreting the estimated coefficients changed;

$x_1 * {}^{1}x_2$ is the product of the variables x_1 and $^{1}x_2$ and was used to measure the effect modification or interaction between x_1 and $^{1}x_2$. It is also a binary variable with values 0 and 1;

$x_1 * {}^{2}x_2$ is the product of the variables x_1 and $^{2}x_2$ and was used to measure the effect modification or interaction between x_1 and $^{2}x_2$. It is also a binary variable with values 0 and 1;

ε represents the error.

The coefficients (model parameters) α, β_1, $^{1}\beta_2$, $^{2}\beta_2$, $^{1}\beta_3$, $^{2}\beta_3$ were to estimate, where:

α is the constant model and represented the average value of the parameter studied in a basin (basin receiving duckweed) before the introduction of duckweed;

β_1 is the difference between the average value of the parameter studied in the period after the introduction of a plant in the basins and that obtained before the period, regardless of the basin;

$^{1}\beta_2$ is the difference between the average value of the parameter studied in the pond water lettuce and that of duckweed pond, regardless of the period;

$^{2}\beta_2$ is the difference between the average value of the parameter studied in the pond water hyacinth and that of duckweed pond, regardless of the period. However, interpretation of $^{1}\beta_2$ and $^{2}\beta_2$ parameters presented little interest, because they did not consider the states of water before and after the introduction of plants.

$^{1}\beta_3$ is the differential between the effect of water lettuce on the parameter of interest and the effect of the lens of water on the same parameter;

$^{2}\beta_3$ is the difference between the effect of water hyacinth on the parameter studied and the effect of duckweed on the same parameter, here the coefficients 1β3et 2β3ont used to compare the treatment capacity of the water by different plants ie duckweed, water lettuce and water hyacinth.

The interpretation of model results was made by analysis of the global significance of the model, the significance of the coefficients of the model and the significance of the interaction of the explanatory variables. The global significance of the model is assessed using the probability (p-value) associated with Fisher's test and allowed to deduct, at least one factor model (different from the constant) was significantly different from zero. The significance of the interaction effect is assessed through Fisher test on all coefficients associated with dummy variables to measure the interaction. This is a post-test, that is to say, a test carried out after the regression.

Purification yields were determined by the following formula:

P: parameter; r : % yield.

$$r = \frac{[P]input - [P]output}{[P]input} \times 100 \quad (1)$$, with :

Results

Characterization of Domestic Wastewater

Domestic wastewater sampled from CUAC on mini STEP meet the standards of reference in organic and inorganic compounds. COD is determined to 508.0 mg O2 / l and 25.3 mg TKN / l. The report DCO/DBO$_5$est equal to 2.7 and reflects a certain biodegradability of these influential (Table 3).

Descriptive analysis of global parameters physicochemical

The descriptive analysis performed shows that the variation coefficients are significant for all variables except temperature and electrical conductivity. This suggests that these variables, except the two listed have fluctuated widely over the days of experimentation (Table 4). Best settings in general are differentially from one basin to another (Fig. 1). Indeed, the maximum average value of pH is observed in the duckweed pond, or 9,57, reflecting activities thus phytoplankton growth of algae in this basin. However, in pools with water hyacinth and water lettuce, a progressive acidification is observed. This acidification is due either to the exudation in the roots of these plants or high evapotranspiration from plants. In addition, the EH in pools with water hyacinth and water lettuce develops negative values to positive ones, for a contact time t_c macrophytes with wastewater that is 11.

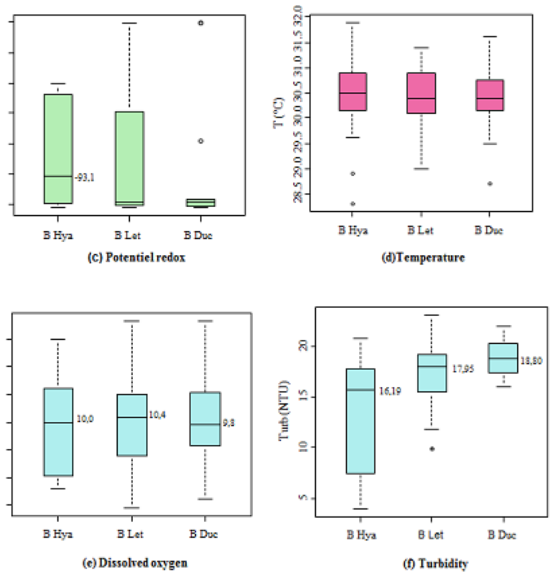

Fig. 3. Physico-chemical parameters of pond effluents floating macrophyte.

Table 1. Standards for determination of global parameters of pollution.

Parameter	Standard
T, pH, EH	NF T 90 – 008
Electrical conductivity	NF EN 27888 (January 1994)
O2	NF T 90 – 106
Turbidity	NF T 90 – 033
MES	NF T 90-105-1 (January 1997)
DCO	NT T 90 – 101
DBO5	NF T 90 – 103
NTK	NF EN 25663(January 1994)
Fecal coliforms and fecal streptococci	NF-08-05 with the environment Rapid-E Coli NFT-90416 with the environment Slanetz (24 h – 48 h à 37 °C)

The average value of dissolved oxygen is almost unchanged from one basin to another (Table 5). Turbidity can differentiate the basin with water hyacinth ponds water lettuce and water lentil with an average of 13.60 NTU and a CV of 0.44. It therefore appears that the water hyacinth on the environment is considerably unlike other species. This result agrees with the work of Lu et al. (2008), who focused instead on the water transparency in the presence of water hyacinth. However, it is recognized a certain correspondence between the turbidity and transparency. The anoxic lagoons macrophytes, an intermediate step between the anaerobic and aerobic, confirms the results of Kone (2002) and Monello (2009) who showed that after a few centimeters from the surface, is an anoxic created by covering the plants. These results herald real physico-chemical reactions in the different lagoons to floating macrophytes.

Estimating the parameters of different models of operation follow

Models of EH, the electrical conductivity (χ), turbidity and dissolved oxygen (O2) are globally significant (Table 5). E_H decreases after the introduction of plants. Their effect on this parameter was significant and differed depending on the plant. Specifically, duckweed and water lettuce had the same effect on the E_H, with an average decrease of 176.7 between the two periods before and after the introduction of these plants, which shows a state of species adaptation in the new ecosystem. Water hyacinth in turn, has a significantly different from that observed with duckweed and water lettuce ($p = 0.012$). In this basin, there was an average increase of 4.39 between the two periods. Similarly to the electrical conductivity, water hyacinth also has an effect significantly different from that observed with duckweed and water lettuce ($p = 0.006$). This assumes that the pollution from progressively mineralize and become assimilated by plants. Their periodic harvesting reduces the electrical conductivity in the middle. The coefficient associated with the variable "period" is negative and significantly different from zero ($p = 0.005$), indicating that oxygen dissolved in the medium decreased after the introduction of each species. But the Fisher test on all coefficients associated with dummy variables of the interaction was not significant (p > F = 0.3810) and therefore does not detect any specific difference of the influence of one species to another on the environment. The same effect of three species of dissolved oxygen is expected because according OUESLATI (2000) its levels in pools with macrophytes were made by photosynthesis and respiration. By cons, Fisher tests on the variable turbidity least show the action of plants in their environment, which is not consistent with the results of descriptive statistics (boxplots). A difference is not made for the period of introduction of plants.

The results of the descriptive analysis coupled with estimates of those models, show the variations caused by the presence of plants in the middle.

Table 2. Summary of coefficients of linear regression model.

Average		Indicator variable 1x2		Indicator variable 2x2	
		Water lentil (0)	Water lettuce (1)	Water lentil (0)	Water Hyacinth (1)
Period (x1)	Before (0)	A	α + 1β2	α	α + 2β2
	After (1)	α + β1	α + β1 + 1β2 + 1β3	α + β1	α + β1 + 2β2 + 2β3

Table 3 a. Characteristics physicochemical overall anaerobic pond.

Parameters	T (°C)	pH	EH (mV)	χ (µS/cm)	Turb (NTU)	O2 (mg/L)
Mean ± SD	31.4 ±1.2	6.32 ±0.32	54.5 ±19.4	516 ±35	45.15 ±33.00	1.5 ±0. 9
Min	29.6	5.84	21.7	428	6.31	0.5
Max	33.0	6.87	83.6	552	95.83	3.3

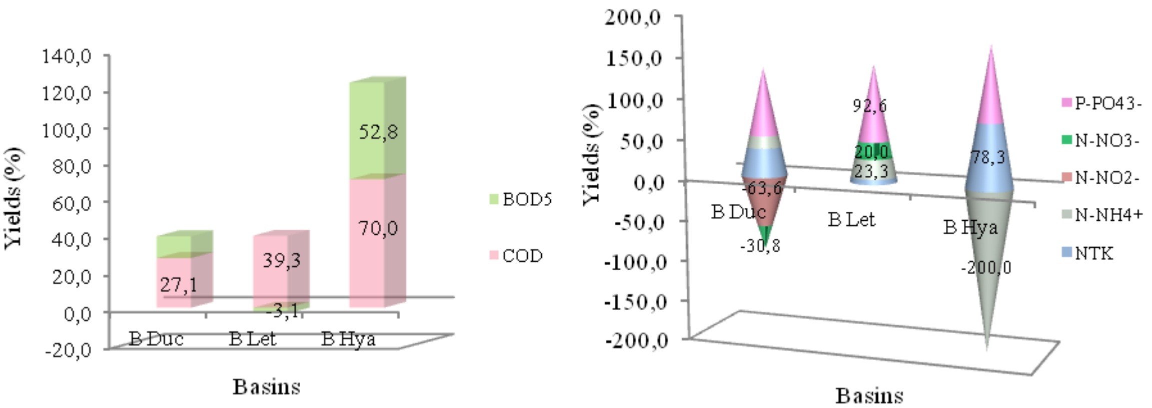

Fig. 4. Purification yields in carbon compounds, nitrogen and phosphorus on river floating macrophyte.

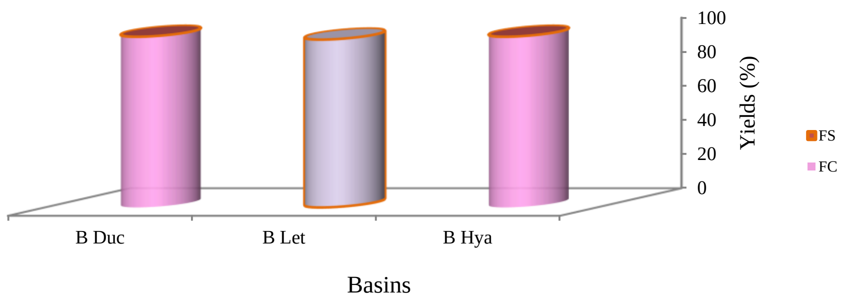

Fig. 5. Yield purification of bio-indicators of floating macrophyte ponds.

Water hyacinth is positioned at the top of the species that has significantly impacted their living environment, by modifying the positive characteristics of the environment. It is effective for the redox potential, electrical conductivity and turbidity. These various data portend a certain purification performance of each species and demonstrates the good progress in symbiotic activities.

Table 3 b. Caractéristics physicochemical overall anaerobic pond.

Parameters	Concentrations
MES (mg/L)	140.0
DCO (mg O2/L)	508.0
DBO5 (mg O2/L)	190.0
NTK (mg/L)	25.3
$N-NH_4^+$(mg/L)	7.3
$N-NO_2^-$ (mg/L)	0.0
$N-NO_3^-$ (mg/L)	0.5
$P-PO_4^{3-}$ (mg/L)	4.6
Fecal coliforms / 100 mL	3,800
Fecal streptococci / 100 mL	8,900

Returns purification performance parameters

The best removal efficiencies of pollution carbon, nitrogen and phosphorus are shared by plants. Yields are in the order of COD and BOD_5: 70% and 52.8%, 39.3% and -3.1%, 11.9% and 27.1% respectively for pools with water hyacinth, to water lettuce and duckweed. The removal rate of DCO obtained for the water hyacinth is in agreement with that obtained by Lu et al. (2008). They found a removal rate of 64.4%, which below that recorded in the present study and justifies by the weather, tropical favorable to the normal expansion of the water hyacinth. An important part of the role of the scrubber water hyacinth and water lettuce is the trapping of these materials, by processes of filtration-adsorption of the root system. Overall, yields of the two plants are similar to NYA et al. (2002) for macrophytes. Returns relating to pollution of nitrogenous and phosphorous are provided by the three species are 92.6% and 91.7% of orthophosphate; Kjeldahl nitrogen (TKN) is best eliminated in the basin of water hyacinth. The studies have confirmed these floating macrophytes absorb directly nutrients and elements from the wastewater and filtrate and absorb the suspended particulates (Lu et al., 2008). Water lettuce makes a greater contribution in reducing nitrogen forms. For nitrate nitrogen, it influences the reduction of its content, with a yield of 27.0%. The improved removal of fecal coliforms and fecal streptococci is provided by the duckweed. This elimination can be explained by sedimentation but also by the effect of repeated harvesting of water lentil, which removes environmental pathogens after a photo-inhibition.

Conclusion

Our study provides a possible choice of species in purifying the implementation of a process ponds using floating macrophytes. On both counts, it also demonstrates the feasibility of estimating the removal performance of a species through evolution models of monitoring parameters of the operation. Our results indicate that:

i) domestic wastewater produced in the dorm F Canadian Campus of Abomey are quite tolerable and charged by the three species tested floating *Eichhornia crassipes* Mart. Solms-Laub. (Water hyacinth), *Pistia stratiotes* L. (Water lettuce) and *Lemna minor* L. (Duckweed);

ii) the three species generally induce physico-chemical reactions in the receiving environment. Water hyacinth and water lettuce act similarly on parameters such as turbidity, electrical conductivity, pH. Particularly for the analysis of the dispersion values of the variables around the mean and the estimated models, there appears a net performance of water hyacinth at least its action in raising the redox potential and the decrease electrical conductivity. However, there is a certain complementarity between these plants. Depending on the emphasis on the elimination of pollution carbon, nitrogen, phosphorus and microbial, water hyacinth is identified best in reducing carbon pollution, followed by water lettuce that provides a significantly contribution in the elimination of nitrogen pollution. Duckweed is more effective in the reduction of pathogens. It is therefore appropriate for the installation of a wastewater treatment plant lagoon to prefer a mixed process composed of these three species.

Table 4: Characteristics monitoring of operating parameters.

Basins	Physico-chemical variables	Average	SD	CV
B Hya	T (°C)	30.4	0.9	0.03
	Ph	8.41	1.43	0.17
	EH (mV)	-70.9	86.4	-1.22
	χ (µS/cm)	485	9	0.02
	Turb (NTU)	13.60	6.04	0.44
	O2 (mg/L)	9.8	3.7	0.37
B Let	T (°C)	30.4	0.7	0.02
	Ph	8.95	1.27	0.14
	EH (mV)	-81.3	100.7	-1.24
	χ (µS/cm)	491	9	0.02
	Turb (NTU)	17.04	4.08	0.24
	O2 (mg/L)	10.5	3.8	0.36
B Dec	T (°C)	30.4	0.7	0.02
	pH	9.57	0.46	0.05
	EH (mV)	-101. 9	105.3	-1.03
	χ (µS/cm)	499	5	0.01
	Turb (NTU)	18.89	1.84	0.10
	O2 (mg/L)	10.4	3.5	0.34

Legend: B Hya = basin with water hyacinth; B Let = basin with water lettuce; B Lent = basin with water lentil; CV = coefficient of variation.

Table 5. Summary of linear regressions.

Parameters p-value	T	pH	EH	X	Turb	O2	RH
Global model	p > F = 0.9166	p > F = 0.1465	p > F = 0.0179	p > F = 0.0003	p > F = 0.0001	p > F = 0.0198	p > F = 0.0882
Coefficient variable period	-	-	p = 0.001	p = 0.310	p = 0.206		
Indicator variable coefficient	p > F = 0.6189	p > F = 0.8588	F = 0.0422	p > F = 0.0219	p > F = 0.1857	p > F = 0.3810	p > F = 0.9941

Legend p = probability turb = turbidity, electrical conductivity χ =; HR = oxidizing power.

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