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Adsorption of Heavy Metal Ions from Aqueous Solutions and Wastewater using Water Hyacinth Powder

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ABSTRACT
The adsorption of heavy metals on water hyacinth powder from both wastewater and aqueous solution was studied using batch experiments. The adsorption efficiency of water hyacinth powder was evaluated in this study. The levels of heavy metals in wastewater were in the range of: 1.2-75.3 ppm for lead, 0.4-87.6 ppm for chromium, 0.1-63.5 ppm for nickel, 0.5-95.5 ppm for zinc and 0.8-52.7 ppm for cadmium. The levels of zinc, lead and cadmium were above the limits set by the write NEMA in full then bracket (NEMA) for discharge into the environment (0.01 ppm for cadmium and lead, 0.5 ppm for zinc). The adsorption efficiency of hyacinth powder was higher in aqueous solution than in wastewater while at low metal concentrations (0.1-3.2 ppm), the adsorption efficiency of water hyacinth powder was 100% in both wastewater and aqueous solution. The study showed that water hyacinth powder is a low cost adsorbent which could be used to remove heavy metals from wastewater and aqueous solution.

KEYWORDS: *Wastewater, aqueous solution, heavy metals, adsorption, Water hyacinth*

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INTRODUCTION

Heavy metals are toxic, non-biodegradable and harmful contaminants that affect human beings and the environment (Azimi *et al.,* 2017). Heavy metal pollution is increasing majorly because of the ever increasing industrialization. Harsh environmental problems which are caused by heavy metals have led to strict guidelines of wastewater release from the industries (Sajab *et al*., 2017). Various methods have been used in the removal of heavy metals from wastewater. However to attain cost-effective industrial wastewater treatment, adsorption can be the inexpensive method which is widely used (Gupta and Mahindrakar, 2015). It involves the transfer of the pollutants from the bulk to the active sites of the adsorbent (Hegazi, 2014). Although activated carbon has huge adsorption capacity, it is an expensive technique. Several studies have reported great adsorption capacity of low cost adsorbent that is comparable to commercial adsorbents (Wani *et al*, 2015). Researchers have been investigating promising adsorbent and their applicability in wastewater treatment (Akbari *et al*., 2015). Comparative study on efficiency of water hyacinth, water lettuce and vetier grass has been reported. The study showed that the three plants have different abilities to eliminate water contaminants and the ability of each plant is influenced by factors such as climate, temperature etc (Gupta and Mahindrakar, 2015). In this study, water hyacinth was used as an economical adsorbent because of its abundance in Kenyan lakes and it requires minimal preparation before use. The aim of this study was to determine the concentration of lead, zinc, cadmium, chromium and nickel in wastewater sampled from different industrial sites in Nairobi and further to evaluate the adsorption efficiency of water hyacinth in the removal of these metal ions from aqueous solution and wastewater.

Material and methods

Water hyacinth was collected from a beach point on Lake Victoria. The water hyacinth stems were sliced into small pieces and washed with water. Distilled water was used to rinse the stems and then dried in the sun for 8 days. The water hyacinth pieces were further dried in an oven 110^{0}C for 24.

The dry fractions of the water hyacinth stem were ground into powder. The particles were then sieved and graded using 300,425 and 2800 µm sieves and stored for subsequent use.

Preparation of the stock solutions

The amount of the reagent to be dissolved in a liter of distilled water to make an aqueous solution whose concentration was 1000 ppm was calculated according to equation 1.

$$\mathbf{M} = \frac{Mw}{Aw} \text{ x } \frac{100}{P} \text{ x } \frac{V}{1000} \qquad (1)$$

where M = mass (g) of the soluble salt which was weighed,

M_W = molecular weight of the salt,
A_w = Atomic mass of the element of interest, V= volume of the stock solution to be made, P= percentage purity of the salt. The calculated amount of metal salt which was weighed is shown in Table1.

Table 1 Amount of salts weighed (g) to make aqueous solution whose concentration was 1000 ppm.

Metal	MF	MW	Amt (g)
Pb	Pb $(NO_3)_2$	331.2	1.6311
Zn	Zn $(NO_3)_2.6H_2O$	297.48	4.7396
Cd	$3CdSO_4.8H_2O$	769.56	6.9861
Cr	$Cr(NO_3)_3.9H_2O$	400.15	7.9347
Ni	Ni $(NO_3).6H_2O$	290.80	5.0560

MF = Molecular formula, MW = molecular wt
Amt = Amount weighed (g)

The amount weighed was then placed in a 1000 ml volumetric flask. 100 ml of distilled water was added and stirred. 30 ml of 1M HNO_3 was added and the solution was swirled. Distilled water was added to the mark.

The working standards for the AAS were obtained from standard commercial solution by dilution. 0.1M HNO_3 and 0.1M NaOH were used to adjust the pH of the stock solutions.

Collection of the wastewater samples
Samples of wastewater were collected from Sites A (Battery manufacturing Company), Site B (Paints manufacturing Company), Site C (Steel manufacturing Company) and Site D (Plastics manufacturing Company) in industrial area in Nairobi County. Sampling was done using pre-cleaned polyethylene bottles that had been washed with distilled water and rinsed with HNO_3 and labeled. The samples were then stored in a refrigerator for subsequent analysis.

Digestion of wastewater samples
300 ml of the wastewater samples were first treated with 3 ml dilute nitric acid, shaken thoroughly and allowed to stand for 24 hrs. The samples were gravity filtered using Whatmann paper (No. 40). The filtrate was shaken well before taking 100 ml which was added to a beaker using a 100ml volumetric flask. To the 100 ml sample, 3.0 ml of acquaregia was added. The resulting mixture was covered using a watch glass.

A blank was also prepared by adding 100 ml of deionized water into a beaker, followed by 3.0 ml of acquaregia and covering the beaker with a watch glass. The samples were heated at 90^0 C for 3 hrs in a fume hood until the volume of the sample was reduced to 20 ml. The samples were allowed to stand for 30 minutes to cool. The watch glass was removed and the sample was dispensed to a 100 ml volumetric flask. Deionized water was added to the samples to make it to 100 ml. The sample was stirred for 5 minute, filtered and the filtrate was used for the determination of heavy metal concentration using AAS.

Determination of heavy metals in the samples using AAS
The standards were then run in the instrument, read and a linear calibration curve for each metal was obtained. The samples were then run in AAS and concentration of heavy metals obtained from linear line.

Removal of heavy metals from wastewater
100 ml of digested sample was added to 0.5g of powdered water hyacinth contained in a series of beakers. The mixtures were stirred continuously for 5 minutes. The samples were allowed to stand for 2 hours for adsorption to occur. The mixtures were filtered and the residual concentration (C_2) of the selected heavy metal ions contained in the filtrate established using the AAS. The adsorption efficiency of water hyacinth in the removal of selected metallic ions from wastewater was computed using Equation (2)

$$q = \frac{C1-C2}{C1} X100 \quad (2)$$

Where q- adsorption efficiency of water hyacinth, C_1- concentration of the selected heavy metals in wastewater; C_2-residual concentration of the selected heavy metals after adsorption

Removal of heavy metals from aqueous solution using water hyacinth
The experiments were carried out using 100 ml of aqueous solutions whose metal concentrations varied from 75.3 ppm for lead, 52.7 ppm for cadmium, 95.5 ppm for zinc, 63.6 ppm for nickel and 87.6 ppm for chromium. Each of the metal concentrations was added to 0.5g (<300 μm) of powdered water hyacinth contained in a series of 500 ml beakers. The mixtures were stirred continuously for 5 minutes and allowed to stand for 2 hours for adsorption to occur.

The mixture was filtered and the concentrations (C_2) of selected heavy metal ions were determined in the filtrate using AAS. The adsorption efficiency of water hyacinth in the removal of selected metallic ions from wastewater was computed using Equation (2).

Results and discussion
Concentration of Heavy metals in wastewater
The concentration of the heavy metals in the wastewater samples at sites A, B, C, and D are shown in Table 2.

Table2. Concentration (mg/l) of heavy metals in wastewater

	Heavy metal concentration (mg/l)				
Site	Pb	Cd	Zn	Ni	Cr
A	68.5 ± 0.1	52.7 ± 0.1	0.75 ± 0.01	0.2 ± 0.02	0.51 ± 0.01
B	75.3± 0.2	40.0 ± 0.5	95.5 ± 0.2	0.14 ± 0.06	0.51 ± 0.01
C	1.2 ± 0.03	0.98 ± 0.1	48.8 ± 0.3	63.5 ± 0.2	87.6 ± 0.5
D	3.2 ± 0.01	0.88 ± 0.6	0.58 ± 0.02	0.11 ± 0.03	0.38 ± 0.01

Site A had very high levels of Pb and Cd. The high concentration of cadmium could be attributed to the use of Cadmium Oxide as a conductor in the manufacture of battery (Klein and Costa, 2007). Lead levels were high because of the use of lead metal and lead oxide as electrodes during manufacturing of batteries (Saaidia *et al.*, 2017). The high zinc concentration in sites B and C could be attributed to the use of ZnO and $ZnCrO_4$ as pigments in the manufacture of white and yellow paints respectively (Osmond, 2012). High Pb concentration in Sites A and B could be ascribed to the use of $Pb(CO_3)_2$ and $PbCrO_4$ in paints (Kessler, 2014). The high concentration of Cadmium in sites A and B could be due to the use of cadmium sulfide as a pigment in the manufacture of the yellow paints (Ogilo *et al.*, 2017). The high concentration of chromium in sites B and C could be attributed to the use of Cr_2O_3 and $Cr_2O_3.H_2O$ as a colorant in chrome green paints (Sabty-Daily, 2017). The high levels of Cr in site C could be as a result of chromium used in steel manufacturing (Nakamura *et al.*, 2017). The high nickel concentration in site C could be attributed to the use of nickel in the manufacture of steel (Abdallah *et al.*, 2017).

Efficiency of water hyacinth powder in the removal of heavy metals from wastewater

The effects of powdered water hyacinth (<300 µm) on the removal of heavy metals in wastewater were investigated and the results are shown in Figures 1-4

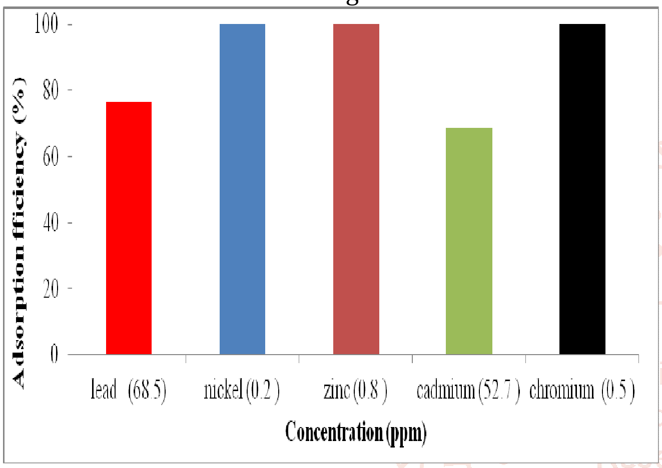

Figure 1: The effects of powdered water hyacinth on the concentration of heavy metals in wastewater collected from site A (Battery manufacturing Company)

Heavy metals with high concentration had lower percent efficiency of removal (Figure 1). This can be ascribed to the competition for the adsorption sites from other metals in the wastewater (Medellin-Castillo *et al*, 2017). This further confirms the effectiveness of water hyacinth powder in the removal of heavy metals in wastewater at low concentrations. Figure 2 shows the efficiency of water hyacinth in the removal of heavy metals from wastewater collected from site B. The trend is also the same as Figure 1.

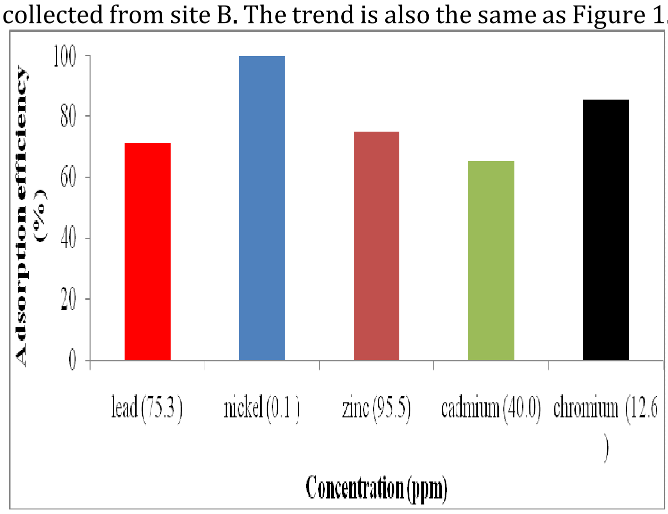

Figure 2: The effects of powdered water hyacinth (<300 µm) on the concentration of heavy metals in waste-water collected from site B (Paints manufacturing Company)

Figure 3 shows the efficiency of water hyacinth in the removal of heavy metals from wastewater collected from site C. Again similar trend was observed.

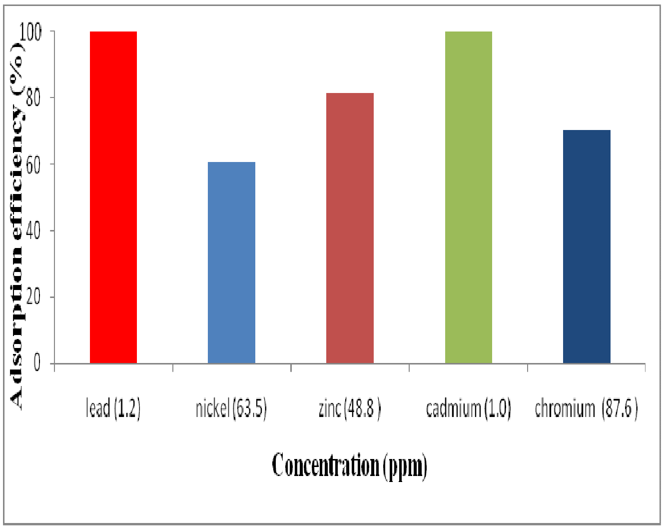

Figure 3: The effects of powdered water hyacinth (<300 µm) on the concentration of heavy metals in waste-water collected from site C (Steel manufacturing Company).

Figure 4 shows the efficiency of water hyacinth in the removal of heavy metals from wastewater collected from site D.

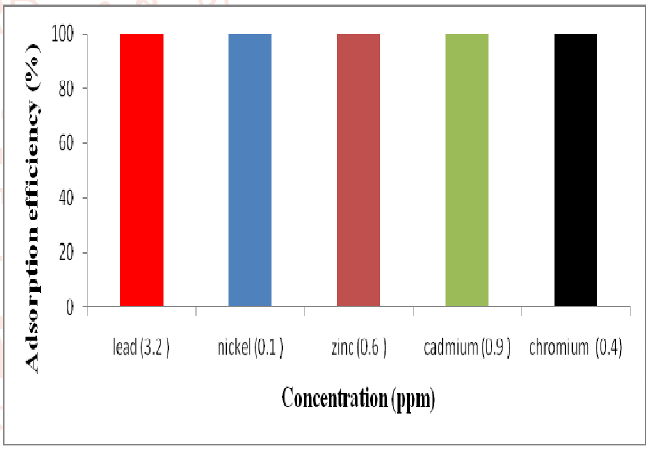

Figure 4: The effects of powdered water hyacinth (<300 µm) on the concentration of heavy metals in waste-water collected from site D (Plastic manufacturing Company).

Adsorption of heavy metals on adsorbent in an aqueous solution

The adsorption studies for heavy metals from an aqueous solution was carried out using the highest concentration for each metal based on the levels that had been determined in the wastewater for the various industrial sites (75.3 ppm for lead, 52.7 ppm for cadmium, 95.5 ppm for zinc, 63.6 ppm for nickel and 87.6 ppm for chromium) as shown in Table 2. The results were used to investigate the percentage efficiency of heavy metal elimination from the aqueous solution by water hyacinth powder as shown in Figure 5.

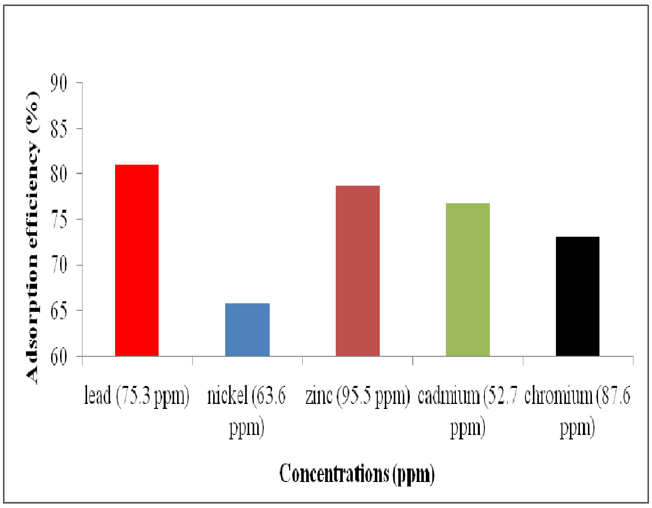

Figure 5: Efficiency of water hyacinth powder in the removal of heavy metals from aqueous solution.

In the studies where percent efficiency of removal of the heavy metals was calculated for the wastewater (Figures 1 to 4), heavy metals with low concentrations had the highest % efficiency removal however in the aqueous solution where individual metal concentrations existed on their own, the removal trend was different (Table 3)

Table 3: Efficiency of water hyacinth powder in the removal of heavy metals from both wastewater and aqueous solution

% Efficiency of Heavy metal removal		
Heavy metal	aqueous solution	wastewater
Nickel (63.6 mg/l)	65.8	60.4
Zinc (95.5 mg/l)	78.7	74.9
Cadmium (52.7 mg/l)	76.9	68.9
Lead (75.3 mg/l)	81.1	71.0
Chromium (87.6 ppm)	73.1	70.2

The study showed that the percent efficiency in the removal of the heavy metal ions was higher in aqueous solution than in the wastewater irrespective of the concentration used. This could be attributed to external competition for the adsorption sites from other metal ions in the wastewater (Park *et al.,* 2015).

Conclusion

The study showed that the levels of zinc, lead and cadmium in wastewater were above the limit recommended by NEMA. The percent efficiency to remove heavy metals from both wastewater and aqueous solutions by water hyacinth powder at low concentrations of heavy metal was higher than at high concentration. Hence, water hyacinth *E.crassipes)* can be used to remove heavy metals in wastewater released from the industries. The adsorption efficiency in aqueous solution was higher than the adsorption efficiency in wastewater. Cd and Pb concentrations in sites A, B were very high; Zn in B, and C were very high; Ni in C was very high; Cr in B and C were very high.

Abbreviations

NEMA: National Environment Management Authority; AAS: Atomic Absorption Spectrophotomer; HNO_3: Nitric acid; NaOH: Sodium hydroxide; pH: potential hydrogen; ppm: parts per million; M: Molarity; Mg/l: milligram per liter; ZnO: Zinc Oxide; $ZnCrO_4$: Zinc Chromate; Pb: Lead; $Pb(CO_3)_2$: Lead Carbonate; $PbCrO_4$: Lead (II) Chromate; Cr_2O_3:Chromium (III) Oxide; $Cr_2O_3.H_2O$ Chromium (III) Oxide hydrate; Cd: Cadmium; Cr: Chromium, Zn: Zinc; Ni: Nickel

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Availability of data and materials

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Authors' contribution

John Onam Onyatta and Amir Okeyo Yusuf designed the experiment. Joseph Munene Mwaniki collected the samples, carried out sample preparation, analysis and wrote the manuscript. John Onam Onyatta and Amir Okeyo Yusuf revised the manuscript critically for intellectual content.

Competing interests

The author declares that they have no competing interest.

References

[1] Abdallah, M., Jahdaly, B.A.A, Salem, M. M., Fawzy, A. and Abdel, F.A.A. (2017) Pitting corrosion of Nickel and stainless steel in chloride solutions and inhibition using inorganic compounds. *JMES* 8:2599-2607 doi:http://www.jmaterenvironsci.com/

[2] Akbari, M Hallajisani, A., Keshtkar, A. R., Shahbeig, H., and Ghorbanian, S.A. (2015).Equilibrium and Kinetic study and modeling of Cu(II)and Co(II) synergistic biosorption from Cu(II)-Co(II) single and binary mixtures of brown algae *C.indica. J.Environ.Chem.Eng.*3:140-149 doi.org/10.1016/j.jece.2014.11.004

[3] Azimi, A., Azari, A., Rezakazemi, M. and Ansarpour, M. (2017) Removal of heavy metals from industrial waste water: A review. *ChemBioEng*1:1-24 doi: 10.1002/cben.201600010

[4] Gupta, P., Roy, S. and Mahindrakar, A. (2015) Removal of heavy metals from waste water using water hyacinth,Water Lettuce and Vetiver Grass. A Review. *IJEEM* 7:11-34 doi: 10.5923/j.re.20120205.04

[5] Hegazi, H.A.(2013). Removal of the characteristics of heavy metal from waste-water by low-cost adsorbents. *HBRC Journal* 9(3):276-282. http://ees.elsevier.com/hbrcj

[6] Kessler, R. (2014) Lead based decorative paints: Where are they still sold and why? *Environ. Health Perspect.* 122(4): 96-103 doi: 10.1289/ehp.122-A96

[7] Klein, C., and Costa, M. (2007). Nickel. In G.F. Nordberg, B.A. Fowler, M. Nordberg, &L. Friberg (EDS.), Handbook on toxicology of metals (3rd ed., pp. 743-758). Academic Press Inc.

[8] Medellin-Castillo, N.A., Padilla-Ortega, E., Regeles-martinez, M.C, Ocampo-Perez, R., Leyva-Ramos, R. and Carranza-Alvarez, C. (2017) Single and competetive adsorption of Cd(II) and Pb(II) ions from aqueous

solution onto industrial chili seeds (*Capscum annum*) *waste. Sustain. Environ. Res.* 27(3):61-69 doi 10.1016/j.serj.2017.01.004

[9] Nakamura, S., Kondo, Y., Nakajima, K., Ohno, H. and Pauliuk, S.(2017) Quantifying recycling and losses of Cr and Ni in steel throughout multiple life cycles using MaTrace-Alloy. *Environ sci techn.* 51(17):9469-9476 doi: 10.1021/acs.est.7b01683

[10] Ogilo, J.K., Onditi, A.O., Salim, A.M. and Yusuf, A.O. (2017) Assessment of levels of heavy metals in paints from interior walls and indoor dust from residential houses in Nairobi City County, Kenya. *Chemical Science Journal* 21:1-7 DOI:10.9734/CSJI/2017/37392

[11] Osmond, G (2012). Zinc white: A review of zinc oxide pigment properties and implications for the stability in oil based paintings. *AICCM* 33(1):20-29 https://doi.org/10.1179/bac.2012.33.1.004

[12] Park, J. H., Cho, J.S., Ok, Y. S., Kim, S. H., Kang, S.W., Choi, I. K., Heo, J. S., Delaune, R. D. and Seo , D. C. (2015) Competitive adsorption and selectivity sequence of heavy metals by chicken bone-derived biochar: Batch and column experiment.

[13] *J Environ Sci Health A Tox Hazard Subst Environ Eng.* 50(11):1194-1204 doi: 10.1080/10934529.2015.1047680.

[14] Saaidia, S., Delimi, R., Benredjem, Z., Mehellou, A., Djemel, A. and Barbari, K. (2017) Use of a PbO_2 electrode of lead-acid battery for the electrochemical degradation of methylene blue *Sep Sci Technol* 52(9):1602-1614 https://doi.org/10.1080/01496395.2017.1291681

[15] Sabty-Daily, R. A., Harris, P. A., Hinds, W. C. and Froines, J.R. (2017). Size distribution and speciation of chromium in paints spray aerosols at an aerospace facility. *Ann Occup Hyg* 49(1):47-59 doi:10.1093/annhyg/meh081

[16] Sajab, M. S., Chia, H. C., Zakaria, S. and Sillanpaa, M. (2017). Adsorption of heavy metals ions on surface of functionalized oil palm empty fruit bunch fibers: Single and Binary systems *Sian Malaysiana* 46(1):157-165. http://dx.doi.org/10.17576/jsm-2017-4601-20

[17] Wani, A. L., Ara, A., and Usmani J. A. (2015) Lead toxicity: A preview. *Interdiscip Toxicol.* 8(2):55-64 doi: 10.1515/intox-2015-0009