

# UNIVERSITY OF ZIMBABWE



## CHEMISTRY DEPARTMENT

### A STUDY OF THE REMOVAL OF Pb, Cd, AND Cr HEAVY METALS FROM AQUEOUS SOLUTIONS BY MORINGA OLIEFERA SEEDS IN COMPARISON TO CARBONIZED MORINGA OLIEFERA SEED.

By

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## **Abstract**

Moringa oleifera is an abundant and economically important plant that is used for many purposes, and is a potential resource in many ways; charcoal production is one of them. The uptake for lead, chromium, and cadmium from aqueous solution using the Moringa oleifera seeds biomass (MOS) and Moringa oleifera seed charcoal (CMOS) was studied. CMOS was prepared from MOS in order to make better use of this biomass material. Batch experiments were conducted under varying MOS/CMOS adsorbent dosages (0.5-1.5g), contact time (30min–6hr) and metal ion concentrations (1-50ppm) for chromium, lead and cadmium. The data for MOS fit well with Langmuir isotherm model for lead (maximum metal uptake ( $Q_m$ ) = 1.281mg/g) and Cadmium (maximum metal uptake ( $Q_m$ ) = 0.168mg/g) whereas CMOS can be modelled by both Freundlich and Langmuir isotherms for chromium (adsorption capacity = 0.2202 mg/g) and Lead (maximum metal uptake ( $Q_m$ ) = 0.552mg/g) respectively. However, the biomass of MOS was found to be more suitable than CMOS for the development of an efficient adsorbent for the removal of chromium, lead and cadmium from aqueous solutions. This study demonstrated that both the charcoal biomass could be used as adsorbents for the treatment of Cr, Pb and Cd from aqueous solution.

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## **Abbreviations**

MOS – Moringa Oleifera seed

CMOS - Moringa Oleifera seed Charcoal

MO - Moringa Oleifera

Conc. – Concentration

Pb - Lead

Cr – chromium

Cd – cadmium

FTIR – Fourier transform infrared

Ca - calcium

DNA – deoxyribonucleic acid

% - percent

ppm – part per million

g – grammes

mg - miligrammes

ml - millilitres

N/A – not applicable

AAS – Atomic absorption spectrometry

$R^2$  – correlation coefficient

## **SECTION ONE:**

### **BACKGROUND OF THE PROBLEM**

Water is a resource that is essential for life and is required by almost every living organism. This resource is however becoming very limited in its pure state due to the many anthropogenic means of contamination which arise from the different advancements made over the years. Metal species released into the environment by technological activities tend to persist indefinitely, circulating and eventually accumulating throughout the food chain, thus becoming a serious threat to the environment. Environment pollution by toxic metals occurs globally through military, industrial, and agricultural processes and waste disposal. (Kumari et al., 2005) This has led to a need of means of purifying / reclaiming of water for the various roles it plays in our lives.

*Moringa oleifera* (Saihjan or drumstick), a cosmopolitan tropical, drought tolerant tree, available throughout the year, has been well documented for its various pharmacological importance, viz. its analgesic, antihypertensive and anti-inflammatory effects. The powdered seed of the plant *Moringa oleifera* has coagulating properties that have been used for various aspects of water treatment such as turbidity, alkalinity, total dissolved solids and hardness. However, its biosorption behaviour for the removal of toxic metals from water bodies has not been given adequate attention. (ibid)

Heavy metals have emerged as the main contaminants of water in recent years. They arise from different sources/activities carried out by industries. Industries which do not implement environmentally friendly industrial waste disposal protocols tend to be the main culprits for the contamination of water as they would just discharge the wastes with disregard to the

future consequences thereof. Unsanitary landfills also contaminate ground water sources with heavy metals which would be from sources like electronics assembly and fabrication, battery manufacturing, paper and pulp industries, metal smelters, textiles, usage of fertilizers and pesticides, and mining activities. There is a need for developing a means of purification of water which is efficient and also cost effective since heavy metals are still toxic to humans even at very low concentrations. Other methods that have been employed are ultra-filtration, reverse osmosis, ion exchange, solvent extraction and chemical precipitation, to mention but a few. (Obuseng, et al., 2012)

## **LITERATURE REVIEW**

### a) Moringa oleifera

*Moringa oleifera* Lam., a medium sized tree species has gained importance due to its multipurpose usage and well adaptability to dry and hot climates of north-western plains, central India and dry regions of peninsular India. (Pandey et al., 2011) The *Moringa Oleifera* (MO) tree is a perennial plant that grows very fast, with flowers and fruits appearing within 12 months after planting. The tree grows up to a height of 5–12 meters with branches extending between 30 and 120 cm. (Arnoldsson et al., 2008). Knowledge that MO seeds can purify water is not new; the seeds have been used for water treatment for generations in countries like India and Sudan. For example, the women of Sudan have used the seeds from the MO tree for water treatment since the beginning of the 20th century through a technique that comprehended the swirling of seeds in cloth bags with water for a few minutes and let it settle for an hour.(ibid)

The value of *Moringa oleifera* for edible pods, seed oil, fodder, and for medicinal use was well known to Indians from the time of immemorial. An exceptionally nutritious vegetable tree with a variety of potential uses was grown as backyard species originally by the

Dravidians (south Indians) and later by the Aryans (north Indians). The genetic resource value of the species finds its entry in the earliest records in Ain-i-Akbari (400 years old) listing of plants used as favourite pickles by the north Indians. Only in last two centuries it was introduced to other parts of the world mainly as an ornamental and multipurpose species. (Pandey et al., 2011) This species has been principally utilized for fruit and leaves as vegetable, and to some extent for edible flowers and seed oil particularly in India, Pakistan, Philippines, Hawaii and many parts of Africa. *Moringa Oleifera* leaves also possess significant antimicrobial activity against gram positive and negative fungal species. (Dahot, 1998)

The oil from the seeds of *Moringa oleifera* is used as edible oil, an excellent salad oil, illuminant, and lubricant, as biofuel and in cosmetic industry. The seeds yield 38–40% of non-drying, sweet, odourless and clear oil that resembles the olive oil. Other multipurpose uses of the species are met from- plant (as hedge and agro/social forestry), leaves (fodder), seeds (seed cake as fertilizer), roots (especially from seedlings; pickle with vinegar), fuel wood (soft, porous and yellowish), bark gum (used for food seasoning and in calico printing), flowers (good source of nectar) and coarse fibre. The seed powder is used in treatment of rheumatism, venomous bites, fever, cardiac and circulatory diseases, abdominal tumours, counter-irritant, external stimulant of skin, purgative, expectorant, mild diuretic, epilepsy and hysteria. The coagulating ability of the seed powder has been used to purify water to make it suitable for drinking in arid regions. It is a cheaper bioabsorbent for removal of heavy metals and organic compounds (ibid; Sharma et al. 2006). MO seed shows good coagulating properties, and has many advantages as it does not affect the pH, alkalinity or conductivity of the water and it can be produced locally at low cost. (Arnoldsson et al., 2008) An indigenous water treatment method uses *Moringa oleifera* seeds in the form of a water-soluble extract in suspension, resulting in an effective natural clarification agent for highly turbid and untreated pathogenic surface water. Efficient reduction (80.0% to 99.5%) of high turbidity produces an

aesthetically clear supernatant, concurrently accompanied by 90.00% to 99.99% (1 to 4 log) bacterial reduction. (Lea, 2010)

MO seed has not only been studied for its coagulating properties but also its removal of heavy metals from aqueous solutions. One such study showed that with an initial cadmium concentration of 7 mg/l, *Moringa oleifera* seed powder, at a dose of 2.50 g/100 ml, reduced the concentration of cadmium by 58%. The increase in initial cadmium (II) concentration resulted in a decrease of percent removal of the cadmium (II). For a fixed dose of the biomass the total available binding sites are limited, thereby binding the same amount of metal ions. This resulted in a decrease in percentage removal of the metal ions as the initial metal ion concentration increases. (Mataka et al., 2010)

In a similar study, *Moringa Stenopetala* (a different species of moringa) was investigated for lead removal by means of jar tests. With an initial lead concentration of 7 ppm, *Moringa stenopetala* seed powder, at doses of 0.50, 1.00, 1.50, 2.00 and 2.50 g/100ml, reduced the concentration of lead by  $20.00 \pm 0.00$ ,  $46.19 \pm 2.06$ ,  $71.19 \pm 2.06$  and  $89.43 \pm 0.60$  and  $96.23 \pm 0.12$  % respectively. The study thus showed that *Moringa stenopetala* seed powder can be used as an effective heavy metal purifier in water. (Mataka et al., 2005)

MO sorption of arsenic has also been studied and showed that maximum sorption for As (III) and As (V) species is 60.21 and 85.6%, respectively. Protein/Amino acid–Arsenic interactions were found to play an important role in the biosorption process using plant biomass of MO. (Kumari et al., 2005)

*Moringa oleifera* (MO) wood, a solid waste has been used and studied for the preparation of activated carbon for the removal of copper, nickel and zinc from synthetic wastewater. Effects of various operating variables namely solution pH, contact time, carbon dose, adsorbate concentration and temperature on the removal of metal ions were studied. The MO

wood charcoal was found to be a promising adsorbent for the removal of Cu, Ni and Zn from aqueous solution. The data from the study showed that the MO wood was an inexpensive, indigenous, easily available material and MO wood charcoal had good potential in treating metal laden industrial effluents. (Kalavathy and Miranda, 2010)

In a relatively similar study, the bark of MO was used to study the biosorption of lead ( $Pb^{2+}$ ) in aqueous solution. Likewise, parameters that influence the biosorption such as pH, biosorbent dose, contact time and concentration of metal ion were investigated. The experimental equilibrium adsorption data were tested by four widely used two-parameter equations, the Langmuir, Freundlich, Dubinin–Radushkevich (D–R) and Temkin isotherms. It was concluded that *M. Oleifera* bark was an effective and efficient biosorbent for removal of  $Pb^{2+}$  ions from aqueous solution. MO bark was considered a viable alternative to activated carbon, ion-exchange-resin and other synthetic adsorbents used for this purpose. (Reddy et al., 2010)

The pods of the MO tree have also been put to the test with respect to sorption of heavy metals. In the study by Bhatti et al., the removal of Zn (II) ions from aqueous solution using pure and chemically pre-treated biomass of *Moringa oleifera* was investigated. The experimental results showed that the maximum pH ( $pH_{max}$ ) for efficient sorption of Zn(II) was  $7 \pm 0.1$  at which evaluated biosorbent dosage and biosorbent particle size, were 0.5 g/L, <0.255 mm, respectively. Both Langmuir and Freundlich isotherm model fitted well to data of Zn (II) biosorption in the study. (Bhatti et al., 2007) The studies above show that every part of the MO tree is very useful.

#### b) Charcoal

Charcoal is produced by the incomplete combustion of plant or animal products. The major use of charcoal is for outdoor cooking. The second largest use of charcoal is in industrial

applications in the form of activated charcoal. The activation process involves heating the charcoal subjecting it to steam or treating with a chemical to both remove substances that have adhered to it as well as break it down into finer particles and thus increase the surface area. Activated carbon has been used for its adsorptive properties as a 'universal antidote' in cases of poisonings, as a filter aid agent, and in decolorization processes. (Utley, 2005)

Activated carbon is a microporous adsorbent that can be produced from a variety of carbonaceous materials, including oak wood (Pehlivan et al.,2011), bamboo (Huang et al., 2012), (Wang et al., 2010), coconut buttons (Anirudhan and Sreekumari, 2011), okra waste (Hashem, 2007), maize cobs (Abdel-Ghani et al., 2007), egg shells (Ghaffar,2008), cocoa shells (Meunier et al., 2003), chitin (Mcafee et al., 2003), pine wood (Mohan et al.,2007), rice husks (Abdel-Ghani et al., 2007), sawdust (Zhang et al., 2001), seed hull (Gueu et al., 2007), and many more. Yadanaparathi et al., have put together a list of adsorbents that can be used to remove heavy metals, namely cadmium, arsenic and lead, from aqueous solution. (Yadanaparathi et al., 2009)

Activated carbons are commonly characterized by the mode of activation. Its unique adsorption properties result from the high-surface area, microporosity, and broad range of surface functional groups. The structure of activated carbon is comprised of carbon atoms that are ordered in parallel stacks of hexagonal layers, extensively cross-linked and tetrahedrally bonded. Several heteroatoms, including oxygen, hydrogen, nitrogen and others, can be found in the carbon matrix, in the form of single atoms and/or functional groups. Oxygen is the dominant heteroatom in the carbon matrix, and the presence of functional groups such as carbonyl, carboxyl, phenol, enols, lactones and quinones, has been postulated. ( El-Hendawy, 2005)

Charcoal has been used in its raw and activated state for the removal of heavy metals from aqueous solution. Several papers have been published in which charcoal from various sources has been used. Most of the sources are agricultural wastes which are formed as by-products of agricultural produce. For example, a number of activated carbons were prepared from a locally available by-product, corncobs, under currently established activation schemes. Obtained carbons were characterized by N<sub>2</sub> adsorption at 77 K and the isotherms were analyzed by BET. The oxidized carbon sample showed relatively higher uptake of Pb<sup>2+</sup> and Methylene Blue and its surface chemistry played the key role in their adsorption, while a sharp decrease was observed in the uptake of phenol and mononitrophenols from aqueous solutions. (El-Hendawy, 2005)

In another study, the potential of oak wood charcoal and oak wood charcoal ash as a low-cost adsorbent for environmental protection applications of Cr (VI) ion was demonstrated. The influence of contact time, solution pH, initial metal concentration, amount of adsorbent and ionic strength on the removal of Cr (VI) ion was studied. It was found that the sorption of Cr (VI) on the adsorbent surface depends strongly on the pH and Cr (VI) ion-sorption increased with a decreasing pH until pH 2 and increase in the concentration of this metal in solution phase. (Pehlivan et al., 2011)

Lalhruaitluanga et al., conducted a comparative study of Lead (II) adsorption from aqueous solutions by raw and activated charcoals of *Melocanna baccifera* Roxburgh (bamboo) and found that the optimum conditions for lead biosorption were almost the same for *M. baccifera* raw charcoal (MBRC) and *M. baccifera* activated charcoal (MBAC)-pH 5.0, contact time 120 min, adsorption capacity  $q_{\max}$  10.66mgg<sup>-1</sup> and 53.76mgg<sup>-1</sup>, respectively. However, the biomass of MBAC was found to be more suitable than MBRC for the development of an efficient adsorbent for the removal of lead (II) from aqueous solutions. FTIR analysis



revealed that –OH, C-H bending, C=O stretching vibration and carbonyl functional groups were mainly responsible for Pb (II) biosorption. Thus, this study demonstrated that both the charcoal biomass could be used as adsorbents for the treatment of Pb (II) from aqueous solution. (Lalhruaitluanga et al., 2010)

Bamboo charcoal has also been used by F.Y. Wang et al., for the adsorption of cadmium (II) ions from aqueous solution. Batch adsorption experiments were conducted and the results showed that the adsorption of Cd (II) ions was very fast initially and the equilibrium time was 6 h. A High pH ( $\geq 8.0$ ) was favourable for the adsorption and removal of Cd (II) ions. Higher initial Cd concentrate ions led to lower removal percentages but higher adsorption capacity. The adsorption behaviour of Cd (II) ions fitted Langmuir, Temkin and Freundlich isotherms well, but followed Langmuir isotherm most precisely, with a maximum adsorption capacity of 12.08 mg/g. This study demonstrated that bamboo charcoal could be used for the removal of Cd (II) ions in water treatment. (Wang, 2010)

### c) Heavy metal toxicity

The pollution of water resources due to indiscriminate disposal of heavy metals has been causing worldwide concern for the last few decades. Unlike organic pollutants, the majority of which are susceptible to bio-degradation, heavy metals are non-degradable to harmless end products. They are toxic to aquatic flora and fauna even in relatively low concentrations. Metals, which are significantly toxic to human beings and ecological environments, include arsenic (As), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), manganese (Mn), cadmium (Cd), nickel (Ni), zinc (Zn) and iron (Fe), etc. Some of these are capable of being assimilated, stored and concentrated by human body, causing erythrocyte destruction, nausea, salivation, diarrhoea, muscular cramps, renal degradation, chronic pulmonary problems and skeletal deformity. (Nadeem et al., 2006)

Ever increasing industrial activity is the main culprit behind most environmental pollution problems and ecosystem damage, coming from the accumulation of pollutants such as toxic metals (chromium, copper, lead, cadmium, zinc, nickel, etc.). Contamination of soils, groundwater, sediments, surface water and air with hazardous and toxic chemicals poses significant problems for both human health and the environment. Heavy metals are considered to be particularly dangerous pollutants. Their presence in the wastewater of several industrial processes, such as electroplating, metal finishing, metallurgical work, tanning, chemical manufacturing, mining and battery manufacturing, has brought about more environmental concerns due to their toxicity even at low concentrations. (Lesmana et al., 2009)

In view of the human health impacts, each metal imparts different effects and symptoms. For instance, Chromium can cause cancer in the digestive tract and lungs. The most common effects on humans apart from lung cancer and death are skin rashes, upset stomachs and ulcers, respiratory problems, weakened immune systems, kidney and liver damage, and alteration of genetic material. (Shanker and Venkateswarlu, 2011) Cadmium also exposes human health to severe risks, as it can provoke cancer, kidney damage, mucous membrane destruction, vomiting, diarrhoea, bone damage, and as well as affect the production of progesterone and testosterone. (Lesmana et al., 2009) Cadmium accumulation leads to Fanconi syndrome, evidenced by tubular necrosis and possible secondary insufficient bone mineralization, glycosuria, polyuria, proteinuria, and aminoaciduria. In humans, this can culminate in development of the painful and debilitating itai-itai disease. Cadmium is a widely used heavy metal that can induce several neuronal dysfunctions in human beings. Interference with calcium and zinc metabolism, cadmium-induced cell death, DNA damage, and oxidative stress are the most frequent effects associated with cadmium exposure. (Mendez-Armenta and Rios, 2011)

Recently, research with human children has been identifying significant risks of cadmium exposure. Effects on motoric and perceptual behaviour are beginning to be identified. It is becoming increasingly apparent that restricting cadmium exposure in utero and in the early years of life is necessary to avoid adverse consequences. Other sources found that low-level, multigeneration exposure to inorganic cadmium can affect functions of the nervous system in rats. This supports possible adverse effects of cadmium on learning ability, although this may not be as pronounced or even evident in animals of a lesser cognitive ability than man. (Phillips and Prankel, 2011)

The toxic effects of Pb in mammals are well documented. Although generally less than 10% of ingested Pb is absorbed from the adult mammalian digestive tract, Pb resembles Ca in atomic structure, and the absorption of Pb can be greatly enhanced when dietary Ca is low. After absorption, Pb metabolism tends to follow Ca metabolism. Like Ca, Pb is stored in bone and other mineralized tissues, and interferes with Ca function in the body. Lead exposure can cause anemia, and it inhibits the enzyme ALA-D, whose measurement in blood is a sensitive indicator of the degree of Pb exposure. Additionally, Pb reacts with proteins in the kidney to form microscopic intranuclear inclusion bodies, and at higher concentrations may cause renal failure. Lead also interferes with the function of the central and peripheral nervous systems, causing lethargy, impaired movement, tremors, and ultimately death. (Scheuhammer et al., 2008)

#### d) Adsorption models

Isotherm adsorption models have been used in waste stream treatment to predict the ability of a certain adsorbent to remove a pollutant down to a specific discharge value. When a mass of adsorbent and a waste stream are in contact for a sufficiently long time, equilibrium between the amount of pollutant adsorbed and the amount remaining in solution will develop. For any

system under equilibrium conditions, the amount of material adsorbed onto the media can be calculated using the mass balance of Equation below:

$$q_e = V \times \frac{C_0 - C_e}{m_s}$$

where  $C_0$  and  $C_e$  (mg/L) are the initial and the final concentrations of adsorbates in flasks, respectively,  $V$  is the volume of the solution (in Litres) and  $m_s$  is the mass of dry adsorbent used (in grammes). (F.Y. Wang et al., 2010)

Adsorption isotherms are important criteria in optimizing the use of adsorbents as they describe the nature of interaction between adsorbate and adsorbent. Thus, analysis of experimentally obtained equilibrium data by either theoretical or empirical equations is useful for practical design and operation of adsorption systems. The Langmuir and Freundlich adsorption isotherms were applied to each metal under study.

### **Langmuir Isotherm**

Langmuir equation relates the coverage of molecules on a solid surface to concentration of a medium above the solid surface at a fixed temperature. This isotherm based on three assumptions, namely adsorption is limited to monolayer coverage, all surface sites are alike and only can accommodate one adsorbed atom and the ability of a molecule to be adsorbed on a given site is independent of its neighbouring sites occupancy. By applying these assumptions, and a kinetic principle (rate of adsorption and desorption from the surface is equal), the Langmuir equation can be written in the following form:

$$Q_e = \frac{Q_m \cdot b \cdot C_e}{1 + bC_e}$$

Where:

- $C_e$  – equilibrium concentration of metal ions in the liquid
- $Q_e$  – equilibrium concentration of metal ions in the solid phase
- $Q_m$  – langmuir constant for maximum metal uptake
- $b$  – langmuir sorption equilibrium constant

The above Langmuir equation is often written in the linear form as follows:

$$\frac{C_e}{Q_e} = \frac{1}{Q_m} C_e + \frac{1}{b \cdot Q_m}$$

$Q_m$  and  $b$  can be calculated from the slope and intercept of the linear plot,  $C_e/q_e$  versus  $C_e$ .

That is,  $Q_m = 1/\text{slope}$  and  $b = 1/(\text{intercept} \cdot Q_m)$ .

### **Freundlich Isotherm**

Freundlich isotherm is an empirical equation. This equation is one among the most widely used isotherms for the description of adsorption equilibrium. Freundlich isotherm is capable of describing the adsorption of organic and inorganic compounds on a wide variety of adsorbents including biosorbent. This equation has the following form:

$$Q_e = K_f C_e^{1/n}$$

Where:

- $Q_e$  and  $C_e$  are the equilibrium concentrations of metal ions in the adsorbed and liquid phases
- $K_f$  is the Freundlich constant characteristic of the system, indicating the capacity
- $n$  is the Freundlich constant characteristic of the system, indicating the adsorption intensity

This equation can also be expressed in the linearized logarithmic form as follows:

$$\log Q_e = \log K_f + \frac{1}{n} \log C_e$$

The plot of  $\log Q_e$  versus  $\log C_e$  has a slope with the value of  $1/n$  and an intercept magnitude of  $\log K_f$ . Thus, the Freundlich constants  $K_f$  and  $n$  can be calculated from the intercept and slope of the linear plot of  $\log q_e$  versus  $\log C_e$ .  $\log K_f$  is equivalent to  $\log Q_e$  when  $C_e$  equals unity. However, in other case when  $1/n \neq 1$ , the  $K_f$  value depends on the units upon which  $Q_e$  and  $C_e$  are expressed. On average, a favourable adsorption tends to have Freundlich constant  $n$  between 1 and 10. Larger value of  $n$  (smaller value of  $1/n$ ) implies stronger interaction between biosorbent and heavy metal while  $1/n$  equal to 1 indicates linear adsorption leading to identical adsorption energies for all sites. This isotherm attempts to incorporate the role of substrate-substrate interactions on the surface. (Febrianto et al., 2009; Reddy et al., 2010)

## **STATEMENT OF THE PROBLEM**

There is a need to study the effectiveness of uptake of heavy metals from aqueous solution by *Moringa Oleifera* seed charcoal as this is not available in literature.

## **SIGNIFICANCE OF THIS RESEARCH**

The findings of this research will be useful in developing the most efficient means of water remediation. With this knowledge apparatus that is relatively cheap and affordable may be developed to purify water of heavy metals that plague most if not all of the water sources in Harare.

## **OBJECTIVES**

- To investigate and compare the uptake of heavy metals from aqueous solutions by moringa oliefera seeds and moringa oliefera seed charcoal by batch adsorption experiment
- To examine the adsorption characteristics at different contact times and concentrations of Cr, Pb and Cd
- To examine the adsorption characteristics with varying amounts of adsorbents
- To fit the data obtained to the Langmuir and Freundlich isotherms
- To determine the better adsorbent between MOS and CMOS with respect to Cr, Pb and Cd

## **SECTION TWO: EXPERIMENTAL PROCEDURES**

### **DELIMITATIONS**

The study was limited to samples synthesized in the laboratory and was focussed primarily on the following heavy metals: lead (Pb), cadmium (Cd), and chromium (Cr) water samples.

### **MATERIALS**

Moringa oliefera seeds were obtained from the Crop Science Department. 1000ppm Standard solutions for the Cr, Cd and Pb were purchased from P&N Scientific Solutions. The metals were analyzed using a Shimadzu AAS6701F spectrophotometer with an air-acetylene flame.

### **METHOD**

#### **a) Pre-treatment of adsorbents**

Dry MO seeds were obtained and stored at room temperature prior to use. The seeds were unshelled by hand and the kernels were washed with copious amounts of distilled water to remove any adhering dirt before drying them in the oven at 65 °C for 24 hrs. The seed kernels were ground to powder using mortar and pestle and the oil was extracted by soxhlet extraction using hexane as the extracting solvent. The powder obtained was dried at room temperature in open air on a bench. The powder was ground to a finer powder using mortar and pestle. A portion of the powder was then be taken and slowly heated until it had been turned to charcoal (CMOS) over a Bunsen burner.

Synthetic metal waters containing metal ions were investigated in batch experiments. Stock metal solutions at various concentrations were prepared by dissolving analytical grade reagents of lead nitrate, cadmium (II) nitrate hexahydrate, chromium standard solution. A solution of known metal ion concentration was prepared and a known quantity of adsorbent



(MOS or CMOS) was added. The mixtures were shaken and the concentration of the unabsorbed metal ions in solutions was determined after separation of the sorbent by centrifugation and filtration using Whatman paper No. 1 filter papers. Cd was determined at 228.8nm with a slit width of 0.5nm. Pb was determined at 216.9nm (slit width = 1.0nm) and 283.3nm (slit width = 0.2nm). Cr was determined at 358nm, 425.7nm and 429nm all with slit width of 0.2nm

**b) Effect of contact time**

A 0.5g mass of MOS was measured into 50ml of 25ppm of Cr metal ions and was left to stand for 30min before it was filtered. The filtrate was then determined by AAS for residual Cr ions in solution. This was repeated at varying times of 1hr, 2hr, 4hr and 6hr. This process was also done using Pb and Cd solutions.

A 0.5g mass of CMOS was measured into 50ml of 25ppm of Cr metal ions and was left to stand for 30min before it was filtered. The filtrate was then determined by AAS for residual Cr ions in solution. This was repeated at varying times of 1hr, 2hr, 4hr and 6hr. This process was also done using Pb and Cd solutions.

**c) Effect of initial metal ion concentration**

A 0.5g mass of MOS was added to a 50ml volume of the Cr metal solution whose concentration was 1ppm. The mixture was allowed to stand for 24hr before it was filtered. . The filtrate was then determined by AAS for residual Cr ions in solution. This was repeated for Cr metal solutions of concentration 5ppm, 10ppm, 25ppm and 50ppm each. This process was also done using Pb and Cd solutions.

A 0.5g mass of CMOS was added to a 50ml volume of the Cr metal solution whose concentrations was 1ppm. The mixture was allowed to stand for 24hr before it was filtered. . The filtrate was then determined by AAS for residual Cr ions in solution. This was repeated for Cr metal solutions of concentration 5ppm, 10ppm, 25ppm and 50ppm each. This process was also done using Pb and Cd solutions.

**d) Effect of dosage**

A 0.5g mass of MOS was added to a 50 ml Cr metal solution of 15ppm and the mixture was left for 24h. The mixture was then filtered and the metal ion concentration of the filtrate was determined using AAS. This was repeated with 1g and 1.5g masses of MOS. The process was then repeated using Pb and Cd solutions.

A 0.5g mass of CMOS was added to a 50 ml Cr metal solution of 15ppm and the mixture was left for 24h. The mixture was then filtered and the metal ion concentration of the filtrate was determined using AAS. This was repeated with 1g and 1.5g masses of CMOS. The process was then repeated using Pb and Cd solutions.

**e) Adsorption Isotherm Studies**

The amount of metal ion sorbed onto the MOS/CMOS,  $Q_e$ , was computed by the following equation:

$$Q_e = \frac{v}{m}(C_0 - C_e)$$

where  $C_0$  and  $C_e$  are the initial and equilibrium concentrations of lead ion in solution whereas  $v$  and  $m$  are solution volume and mass of adsorbent, respectively. Langmuir and Freundlich isotherms were then applied to the experimentally obtained data.

## **SECTION THREE: RESULTS AND DISCUSSION**

### **EFFECT OF INITIAL CONCENTRATION OF CHROMIUM (Cr)**

Table 1 shows the results obtained after the determination using AAS for the MOS and CMOS runs. Some of the solutions required dilution so that they would fall within the linear dynamic region for the determination.

Table 1: Chromium percentage removed by MOS and CMOS in solutions of different initial concentration

<b>INITIAL CONC.</b>	<b>SAMPLES</b>	<b>AVERAGE ABSORBANCE</b>	<b>RECORDED CONC.</b>	<b>DILUTION FACTORED CONC.</b>	<b>% REMOVED</b>
1	MOS 1	0.0221	-0.2011494	-0.20	120.11494
5	MOS 5	0.098	4.16091954	4.16	16.781609
10	MOS 10	0.1922	9.57471264	9.57	4.2528736
25	MOS 25	0.4202	22.6781609	22.68	9.2873563
50	MOS 50 (DIL x5)	0.1621	7.84482759	39.22	21.551724
1	CMOS 1	0.0132	-0.7126437	-0.71	171.26437
5	CMOS 5	0.0492	1.35632184	1.36	72.873563
10	CMOS 10	0.0967	4.0862069	4.09	59.137931
25	CMOS 25	0.1159	5.18965517	5.19	79.241379
50	CMOS 50	0.3487	18.5689655	18.57	62.862069

At low concentrations, both MOS and CMOS are effective in removing Cr from solution. The curves (fig. 1 & fig. 2) show that the CMOS was more effective than MOS over a large

concentration range for Cr ions in solution. CMOS generally maintained a percentage removal that was greater or equal to 60% for a concentration range of 10-50ppm. MOS, on the other hand, was limited to about 20% removal for the same interval.

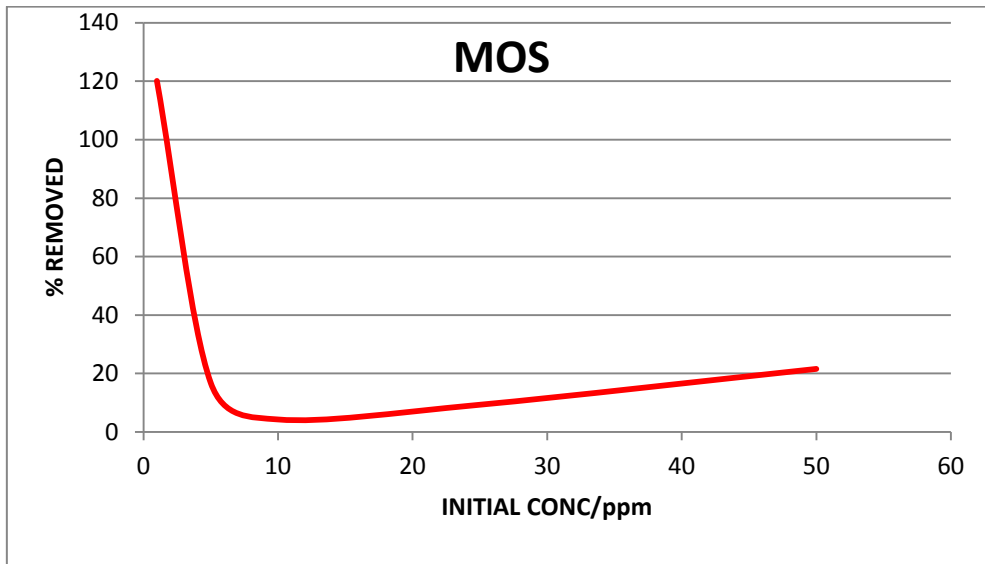


Figure 1: Effect of Initial concentration of Chromium on metal removal using 0.5 g MOS powders

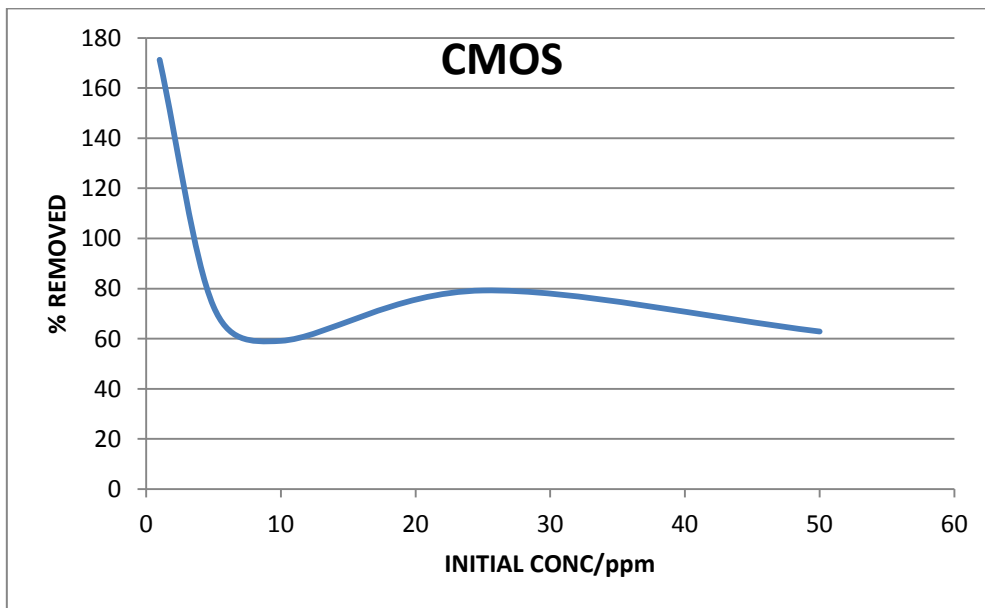


Figure 2: Effect of Initial concentration of Chromium on metal removal using 0.5 g CMOS powders

The greater surface area in the CMOS may be the reason for its superior effectiveness. As the concentration is increase the percentage removal of both curves decreases for both

curves. For a fixed dose of the biomass the total available binding sites are limited, thereby binding the same amount of metal ions. This results in a decrease in percentage removal of the metal ions as the initial metal ion concentration increases. The enhanced metal uptake with an increase in initial metal ion concentration might be due to the increase in the ratio of initial number of moles of chromium ions to the available surface area of the powders. (Mataka et.al, 2010)

## **EFFECT OF INITIAL CONCENTRATION OF LEAD (Pb)**

Table 2 shows the results obtained after the determination using AAS for the MOS and CMOS runs. Some of the solutions required dilution so that they would fall within the linear dynamic region for the determination.

**Table 2:** Pb percentage removed by MOS and CMOS in solutions of different initial concentration

<b>INITIAL CONC/ppm</b>	<b>SAMPLES</b>	<b>AVERAGE ABSORBANCE</b>	<b>RECORDED CONC.</b>	<b>DILUTION FACTORED CONC.</b>	<b>% REMOVED</b>
1	MOS 1	0.0018	-0.342105263	-0.34	134.21053
5	MOS 5	0.014	0.460526316	0.46	90.789474
10	MOS 10	0.0208	0.907894737	0.91	90.921053
25	MOS 25	0.1888	11.96052632	11.96	52.157895
50	MOS 50 (DIL X5)	0.0876	5.302631579	26.51	46.973684
1	CMOS 1	0.0036	-0.223684211	-0.22	122.36842
5	CMOS 5	0.0415	2.269736842	2.27	54.605263
10	CMOS 10	0.115	7.105263158	7.11	28.947368
25	CMOS 25	0.3073	19.75657895	19.76	20.973684
50	CMOS 50 (DIL X5)	0.1304	8.118421053	40.59	18.815789

The figures 3 and 4 show that both sorbents are very effective in removing lead (Pb) ions in low concentrations. The efficiency is then reduced as the concentrations increase. As highlighted earlier in the case of Cr, for a fixed dose of the biomass the total available binding sites are limited, thereby binding the same amount of metal ions. This results in a

decrease in percentage removal of the metal ions as the initial metal ion concentration increases. (Mataka et.al, 2010)

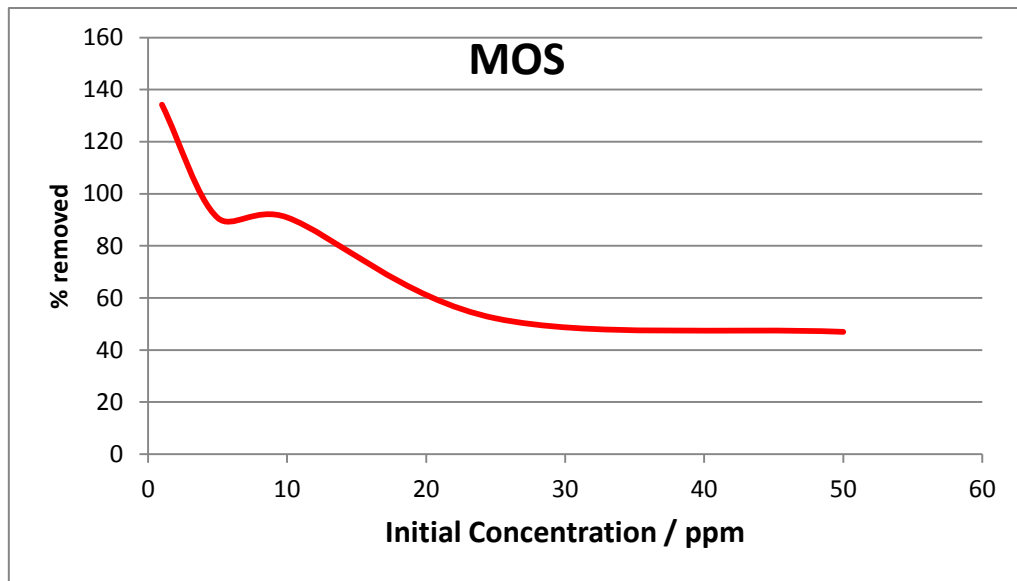


Figure 3: Effect of Initial concentration of Lead on metal removal using 0.5 g MOS powders

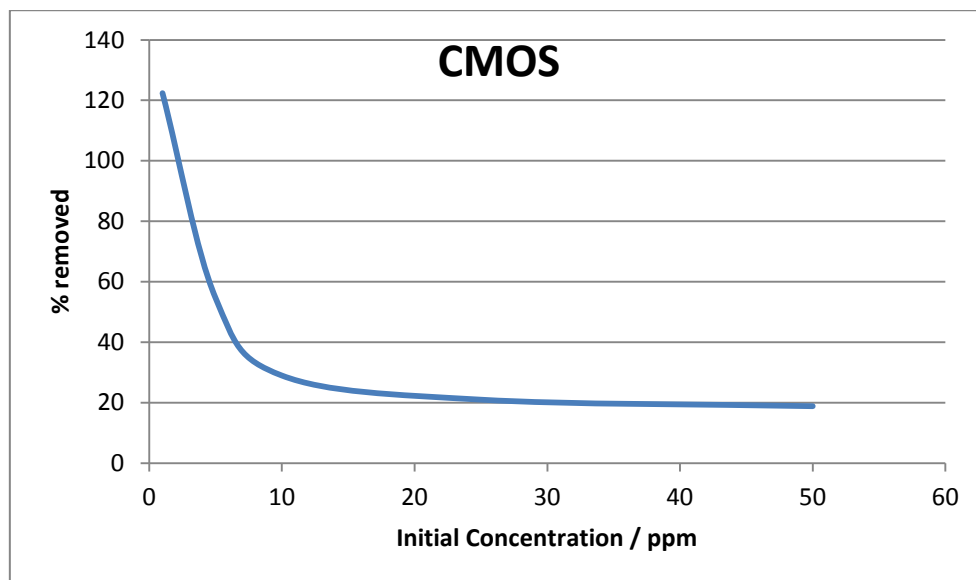


Figure 4: Effect of Initial concentration of Lead on metal removal using 0.5 g CMOS powders



The MOS curve showed that it was more effective than CMOS over a large concentration range. The MOS curve leveled at about 47% removal in a 50ppm Pb solution whilst that of CMOS was about 19%. This result showed that the functional groups found in the MOS are more effective than the CMOS high surface area when it comes to binding Pb ions from solution.

**EFFECT OF INITIAL CONCENTRATION OF CADMIUM (Cd)**

Table 3 shows the results obtained after the determination using AAS for the MOS and CMOS runs. Some of the solutions required dilution so that they would fall within the linear dynamic region for the determination.

Table 3: Cadmium (Cd) percentage removed by MOS and CMOS in solutions of different initial concentration

<b>INITIAL CONC/ppm</b>	<b>SAMPLES</b>	<b>AVE ABSORBANCE</b>	<b>RECORDED CONC.</b>	<b>DILUTION FACTORED CONC.</b>	<b>% REMOVED</b>
1	MOS 1	0.0978	0.330058939	0.33	66.994106
5	MOS 5 (DIL X5)	0.3276	0.97502105	4.88	2.497895
10	MOS 10 (DIL X10)	0.3347	0.994948077	9.95	0.5051923
25	MOS 25 (DIL X25)	0.3094	0.9239405	23.10	7.60595
50	MOS 50 (DIL X50)	0.3384	1.005332585	50.27	-0.533258
1	CMOS 1	0.1715	0.536907101	0.54	46.30929
5	CMOS 5 (DIL X5)	0.1308	0.422677519	2.11	57.732248
10	CMOS 10 (DIL X10)	0.3251	0.968004491	9.68	3.1995509
25	CMOS 25 (DIL X25)	0.3402	1.010384507	25.26	-1.038451
50	CMOS 50 (DIL X50)	0.3579	1.060061746	53.00	-6.006175

The graphs below (figures 5 and 6) show that both sorbents are effective in removing Cd that is in low concentrations. The efficiency of removal of cadmium ions by both MOS and CMOS is very low at concentrations that are above 10ppm. This shows that cadmium ions are not adsorbed as well as chromium and lead ions from aqueous solution over a large concentration range. The total available binding sites for the cadmium ions may be much less as those for chromium and lead resulting in the reduced efficiency. The CMOS curve (figure 6) shows that no significant amount of cadmium ions was adsorbed to reduce the concentration of the solutions above 10ppm, therefore all available binding sites were occupied and full capacity was reached. A probable reason for this is that cadmium ions are only adsorbed as a monolayer on the surface of the CMOS as described by the Langmuir isotherm.

The MOS curve (figure 5) shows enhanced metal uptake with an increase in initial metal ion concentration. This might be due to the increase in the ratio of initial number of moles of chromium ions to the available surface area of the powders. Examples of this phenomenon have been reported in literature on other metal ion-sorption using wild cocoyam and steam activated sulphurised activated carbon prepared from sugarcane bagasse pith (Horsfall and Spiff, 2004; Krishnan and Anirudhan, 2003).

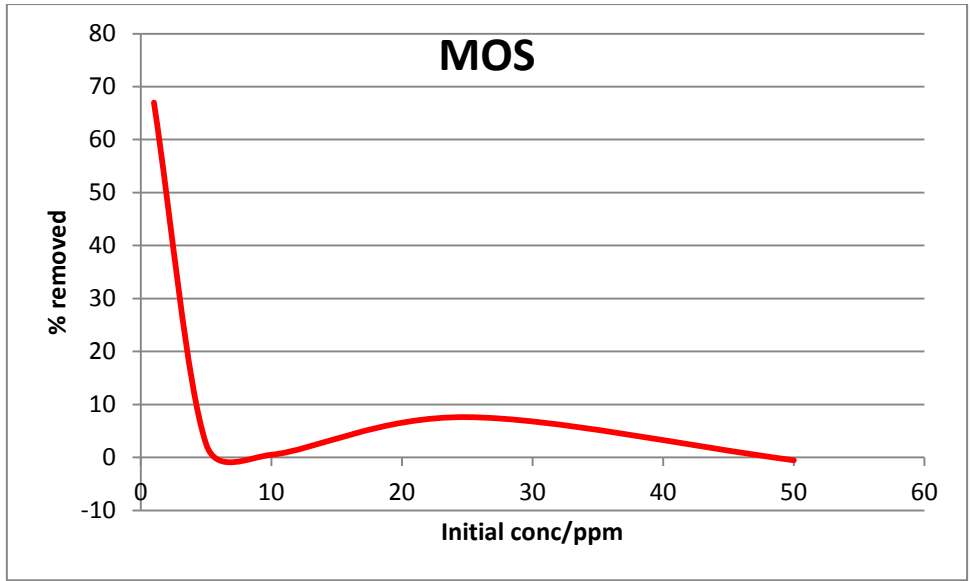


Figure 5: Effect of Initial concentration of Cadmium on metal removal using 0.5 g MOS powders

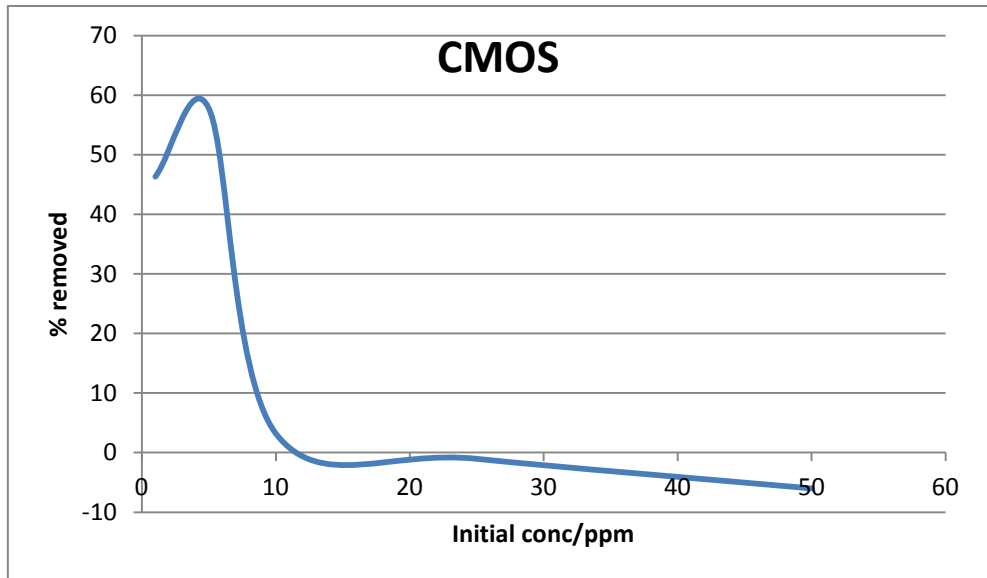


Figure 6: Effect of Initial concentration of Cadmium on metal removal using 0.5 g CMOS powders

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## **EFFECT OF CONTACT TIME ON CHROMIUM REMOVAL**

Table 4 shows the results obtained after the determination using AAS for the MOS and CMOS runs of effect of contact time on removal of chromium ions from aqueous solution.

Table 4:      Effect of contact time on removal of chromium ions from aqueous solution by  
MOS and CMOS

<b>TIME/Hr</b>	<b>SAMPLE</b>	<b>ABSORBANCE</b>	<b>CONC. / ppm</b>
0.5	MOS 30min	0.1919	49.974
1	MOS 1hr	0.1551	40.538
2	MOS 2hr	0.1548	40.462
4	MOS 4hr	0.1566	40.923
6	MOS 6hr	0.1594	41.641
0.5	CMOS 30min	0.051	13.846
1	CMOS 1hr	0.0526	14.256
2	CMOS 2hr	0.0531	14.385
4	CMOS 4hr	0.0638	17.128
6	CMOS 6hr	0.0745	19.872

The curve in figure 7 shows that in the first 30 minutes the initial concentration of Cr ions in solution was raised to almost double that of the initial concentration of 25ppm. This increase could be the result of ions that are found in the MOS which interfere with absorption line of the Cr. An example of such a release was reported by Apiratikul et al., in which Ca (II), Mg (II), and Mn (II) were the major ions released from the algal biomass during the sorption. This revealed that one of the sorption mechanisms was that of ion exchange. (Apiratikul

Pavasant, 2008) The MOS must have also behaved in a similar fashion and released the ions it possesses naturally. Despite the presence of interference, the action of absorption of Cr ions by the MOS was observed as shown in figure 7.

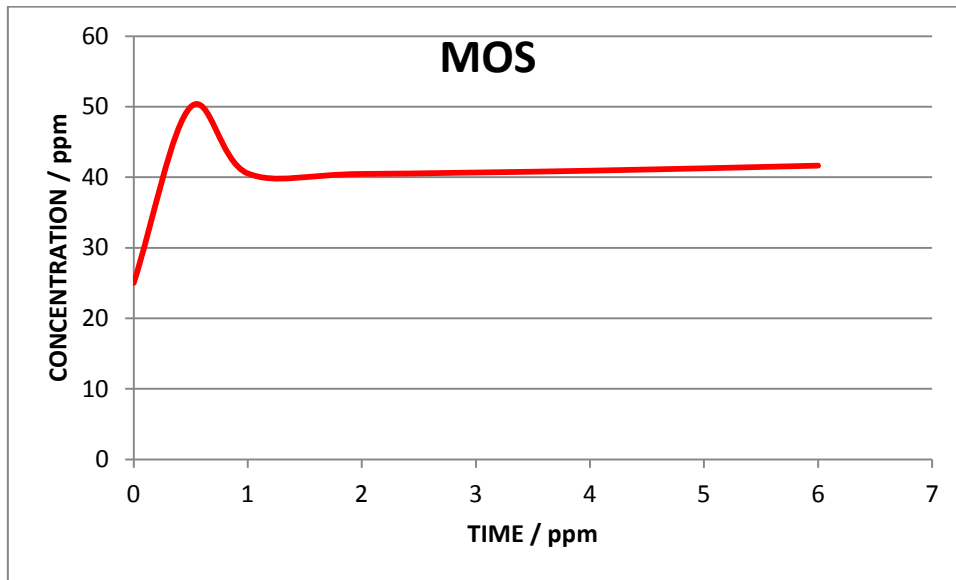


Figure 7: Effects of contact time on chromium removal using 0.5 g MOS powders at initial chromium concentration of 25mg/L

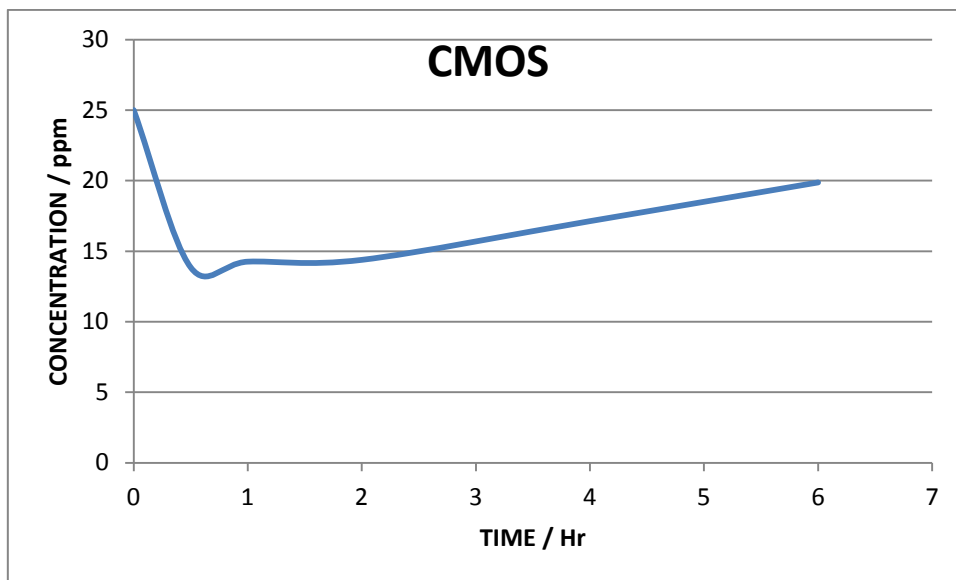


Figure 8: Effects of contact time on chromium removal using 0.5 g CMOS powders at initial chromium concentration of 25mg/L

The curves in figures 7 and 8 generally show that there is rapid uptake in the first hour which is followed by a slow release of the Cr ions back into the solution. This behaviour may be attributed to saturation of the available adsorption sites present on the MOS. That is, the decrease in concentration seized due to the saturation of adsorption sites. After all the sites were occupied the Cr ions were then slowly released back into the solution. The high charge density and small size of Cr ions results in them being strongly hydrolysed by water. Thus the solution will compete with the binding sites for the Cr ions resulting in the slow release with time. ( Mataka et al., 2010)

## EFFECT OF CONTACT TIME ON LEAD REMOVAL

Table 5 shows the results obtained after the determination using AAS for the MOS and CMOS runs of effect of contact time on removal of lead ions from aqueous solution.

Table 5: Effect of contact time on removal of lead ions from aqueous solution by MOS and CMOS

<b>TIME / Hr</b>	<b>Sample</b>	<b>Absorbance</b>	<b>CONC / ppm</b>
0.5	MOS 30min	0.4124	19.401
1	MOS 1hr	0.4107	19.315
2	MOS 2hr	0.378	17.655
4	MOS 4hr	0.343	15.878
6	MOS 6hr	0.3104	14.223
0.5	CMOS 30min	0.5263	25.183
1	CMOS 1hr	0.5227	25.000
2	CMOS 2hr	0.5352	25.635
4	CMOS 4hr	0.5299	25.365
6	CMOS 6hr	0.5353	25.640

The MOS curve below in figure 9 shows that Pb ions continue to be taken up by MOS as the contact time is increased. MOS can thus be left for prolonged time to increase the overall Pb ions absorbed. The rate of uptake is initial very fast in the first half an hour, and it then slows down with time. The decrease in the rate of sorption can be attributed to the smaller ratio of free binding sites to free ions in the solution. The CMOS curve in figure 10 shows that it is not effective in absorbing the Pb ions



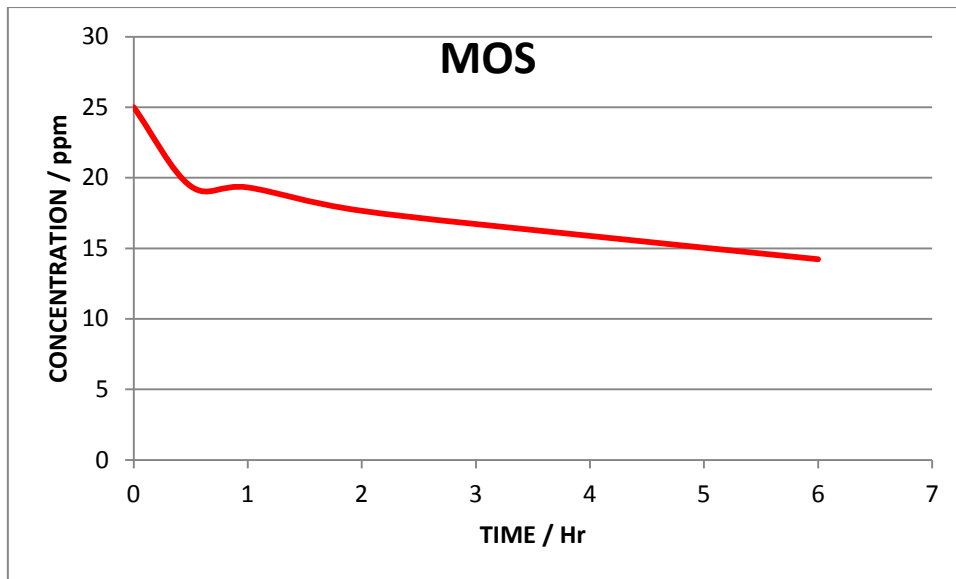


Figure 9: Effects of contact time on Lead removal using 0.5 g MOS powders at initial lead concentration of 25mg/L

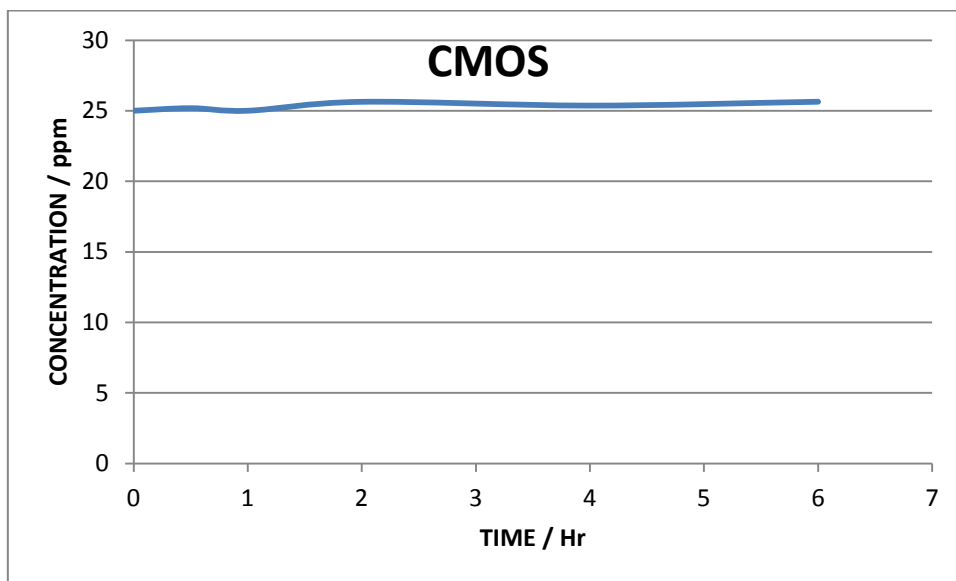


Figure 10: Effects of contact time on Lead removal using 0.5 g CMOS powders at initial lead concentration of 25mg/L

## **EFFECT OF CONTACT TIME ON CADMIUM REMOVAL**

Table 6 shows the results obtained after the determination using AAS for the MOS and CMOS runs of effect of contact time on removal of cadmium ions from aqueous solution.

Table 6: Effect of contact time on removal of cadmium ions from aqueous solution by MOS and CMOS

<b>Time</b>	<b>Sample</b>	<b>Absorbance</b>	<b>CONC / ppm</b>
0.5	MOS 30min	0.4326	0.768
1	MOS 1hr	0.4947	0.893
2	MOS 2hr	0.51	0.924
4	MOS 4hr	0.5294	0.963
6	MOS 6hr	0.5375	0.979
0.5	CMOS 30min	0.5511	1.007
1	CMOS 1hr	0.5251	0.954
2	CMOS 2hr	0.5339	0.972
4	CMOS 4hr	0.5312	0.967
6	CMOS 6hr	0.5316	0.968

The general trend that is seen for MOS in figure 11 is that the concentration initially had been brought down below the initial concentration of 25ppm but started going up as the contact time was increased. Similar trends were observed in literature (eg, biosorption of silver ions to alfalfa biomass (Herrera et al., 2003)). This can be ascribed to the formation of less stable complexes, which easily break as the contact time increases. The weakness of cadmium-Moringa complexes is enhanced by the fact that cadmium due to its high charge density and

small size is strongly hydrolysed by water. This results in competition for cadmium between water and the binding sites on the Moringa. Hence with the increase in contact time cadmium ions go back into the aqueous solution.

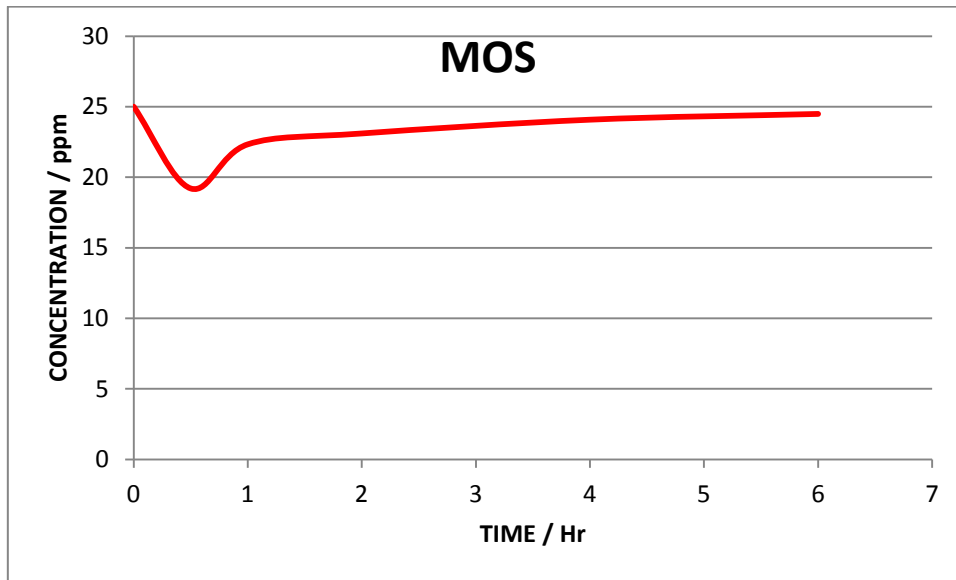


Figure 11: Effect of contact time on cadmium removal using 0.5 g MOS powders at initial cadmium concentration of 25mg/L

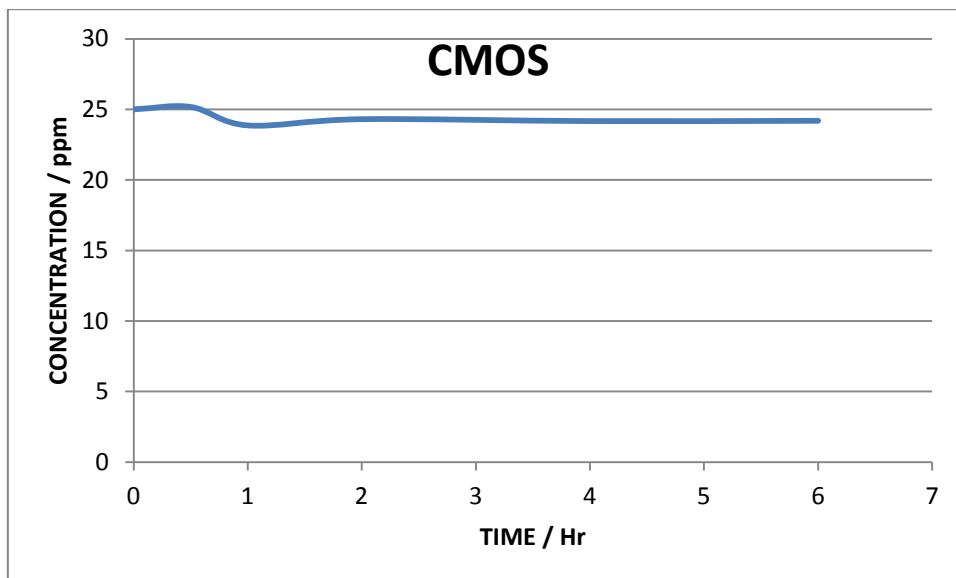


Figure 12: Effect of contact time on cadmium removal using 0.5 g CMOS powders at initial cadmium concentration of 25mg/L

The same phenomenon is observed with the CMOS (Figure 12), where there is rapid uptake in the first hour which is followed by a reverse action in the second hour before equilibration

occurs from after 3hrs. At a time after 6hrs, both MOS and CMOS have about the same concentration of about 24ppm though MOS showed more effectiveness in the early hours where it reduced the Cd ion concentration to below 20ppm.

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## EFFECT OF DOSAGE ON CHROMIUM REMOVAL

Table 7 shows the results obtained after the determination using AAS for the MOS and CMOS runs of effect of dosage of adsorbent on removal of chromium ions from aqueous solution.

Table 7: Effect of dosage on removal of chromium ions from aqueous solution by MOS and CMOS

<b>Mass of sorbent / g</b>	<b>Initial concentration/ ppm</b>	<b>Sample</b>	<b>Absorbance</b>	<b>Concentration / ppm</b>	<b>% removed</b>
0	15	N/A	0	15	0
0.5	15	MOS	0.2677	27.9574	-86.382979
1	15	MOS	0.218	22.6702	-51.134752
1.5	15	MOS	0.2149	22.3404	-48.93617
0	15	N/A	0	15	0
0.5	15	CMOS	0.1388	14.2447	5.035461
1	15	CMOS	0.1314	13.4574	10.283688
1.5	15	CMOS	0.1237	12.6383	15.744681

Though the interference for chromium persisted in MOS, the plotted results in figure 13 show a decrease in concentration as the mass of the sorbent is increased. The CMOS curve (figure 14) was a straight line as the concentration decrease was directly proportional to the increase in sorbent mass. This phenomenon is expected since the metal uptake capacity of the adsorbent increases with the increase in dosage as the number of active sites available for metal increases with increase in the amount of adsorbent.

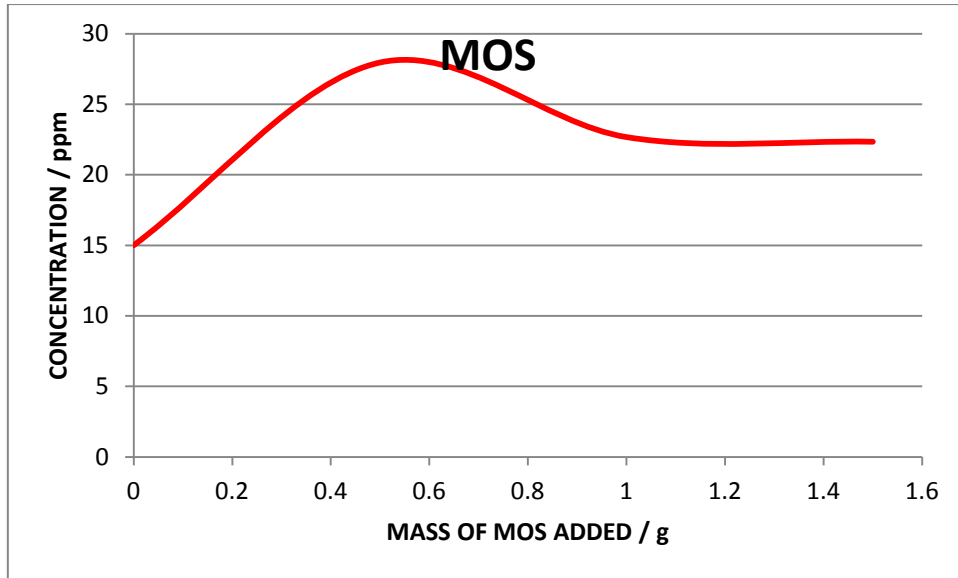


Figure 13: Effect of dosage of MOS powders on removal of chromium ions at initial chromium concentration of 15 mg/L

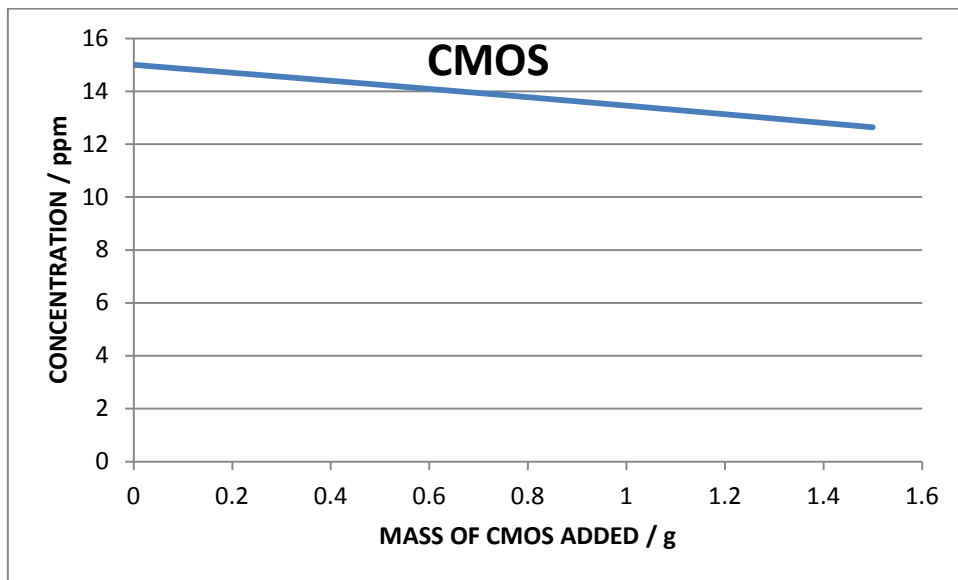


Figure 3: Effect of dosage of CMOS powders on removal of chromium ions at initial chromium concentration of 15 mg/L

## **EFFECT OF DOSAGE ON LEAD REMOVAL**

Table 8 shows the results obtained after the determination using AAS for the MOS and CMOS runs of effect of dosage of adsorbent on removal of lead ions from aqueous solution.

**Table 8:** Effect of dosage on the removal of lead ions from aqueous solution by MOS and CMOS

<b>Mass of sorbent / g</b>	<b>Initial concentration / ppm</b>	<b>Sample</b>	<b>Absorbance</b>	<b>Concentration</b>	<b>% removed</b>
0	15	N/A	0	15	0
0.5	15	MOS	0.2425	2.476851852	83.4876543
1	15	MOS	0.1298	-0.131944444	100.87963
1.5	15	MOS	0.1426	0.164351852	98.904321
0	15	N/A	0	15	0
0.5	15	CMOS	0.7515	14.25925926	4.9382716
1	15	CMOS	0.7470	14.15393519	5.6404321
1.5	15	CMOS	0.735	13.87731481	7.4845679

The MOS curve (figure 15) for lead also decreased rapidly in response to increasing dosage of MOS. The line however started to curve when the Pb ions were left in very low concentration. The linear part of the curve could have continued had the initial concentration been higher. The linearity was lost because the Pb ions had been depleted.

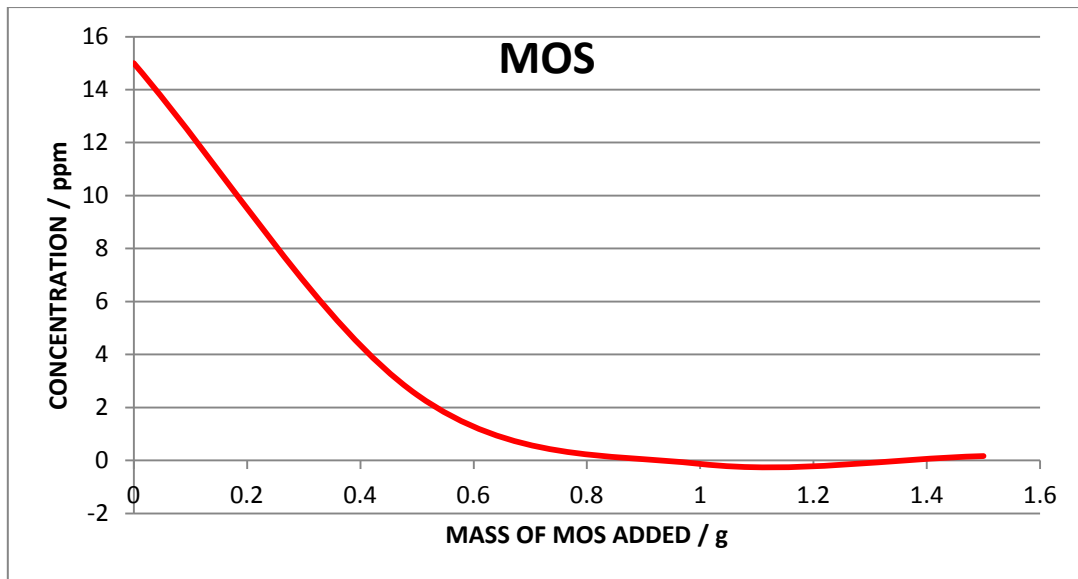


Figure 4: Effect of dosage of MOS powders on removal of lead ions at initial lead concentration of 15 mg/L

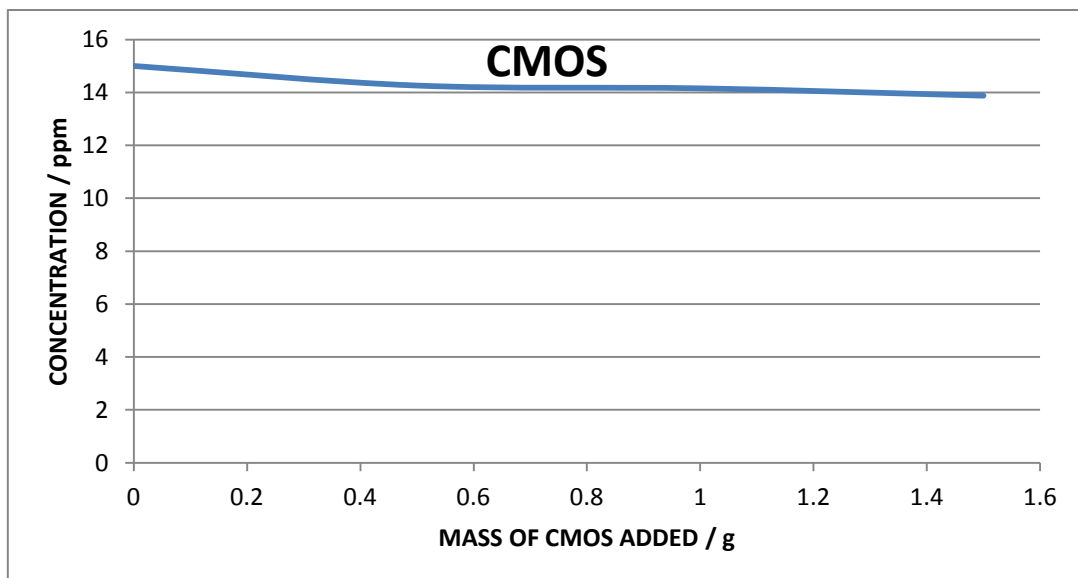


Figure 16: Effect of dosage of CMOS powders on removal of lead ions at initial lead concentration of 15 mg/L

The CMOS also showed a curve (figure 16) which somewhat leveled or slowed down as the mass of CMOS was increased between 0.6g - 1.0g. This shows that the mass at this range has no significant effect on the concentration of the Pb ions. The results show that the MOS is more effective in lead removal than the CMOS with increasing dosage. The percentage removal by 1.5g of MOS was greater than 98% whilst that of CMOS was about 7.5% for the same mass.



## **EFFECT OF DOSAGE ON CADMIUM REMOVAL**

Table 9 shows the results obtained after the determination using AAS for the MOS and CMOS runs of effect of dosage of adsorbent on removal of cadmium ions from aqueous solution.

Table 9: Effect of dosage on the removal of cadmium ions from aqueous solution by MOS and CMOS

<b>Mass of sorbent / g</b>	<b>Initial concentration / ppm</b>	<b>Sample</b>	<b>Absorbance</b>	<b>Concentration / ppm</b>	<b>% removed</b>
0	15	N/A	0	15	0
0.5	15	MOS	0.7358	14.0716	6.1891787
1	15	MOS	0.5192	9.85598	34.293499
1.5	15	MOS	0.3262	6.09965	59.335669
0	15	N/A	0	15	0
0.5	15	CMOS	0.7874	15.0759	-0.5060335
1	15	CMOS	0.7970	15.2627	-1.7516543
1.5	15	CMOS	0.8034	15.3873	-2.5820682

The MOS Cd curve (figure 17) shows a slow concentration change in response to small amounts of MOS added. The curve then slopes down more intensely with the addition of more sorbent. The curve for the CMOS (figure 18) however shows no significant change on increasing the dosage of CMOS. This is probably due to the long time allotted of 24hrs. The Cd ions were most probably released back into solution as discussed above in the effect of time.

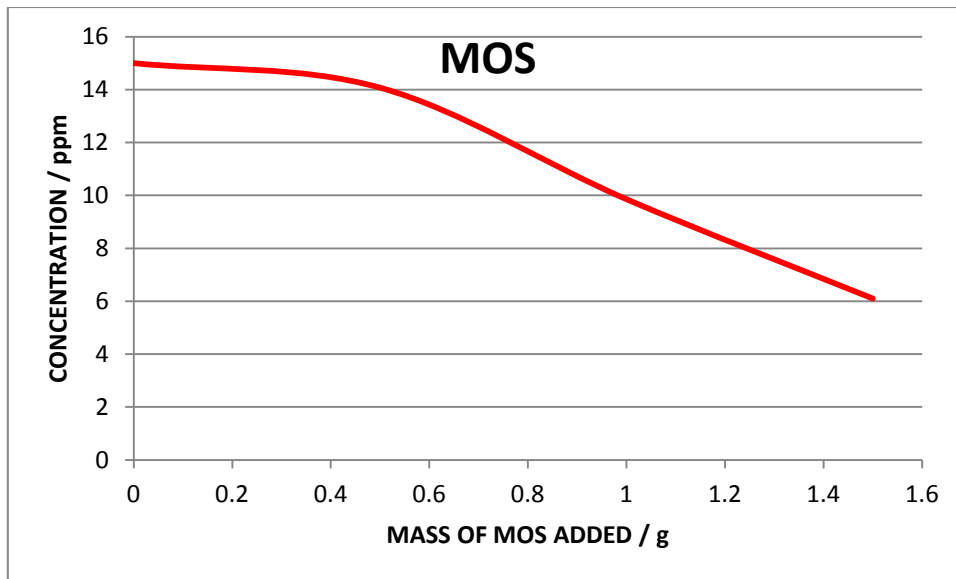


Figure 57: Effect of dosage of MOS powders on removal of cadmium ions at initial cadmium concentration of 15 mg/L

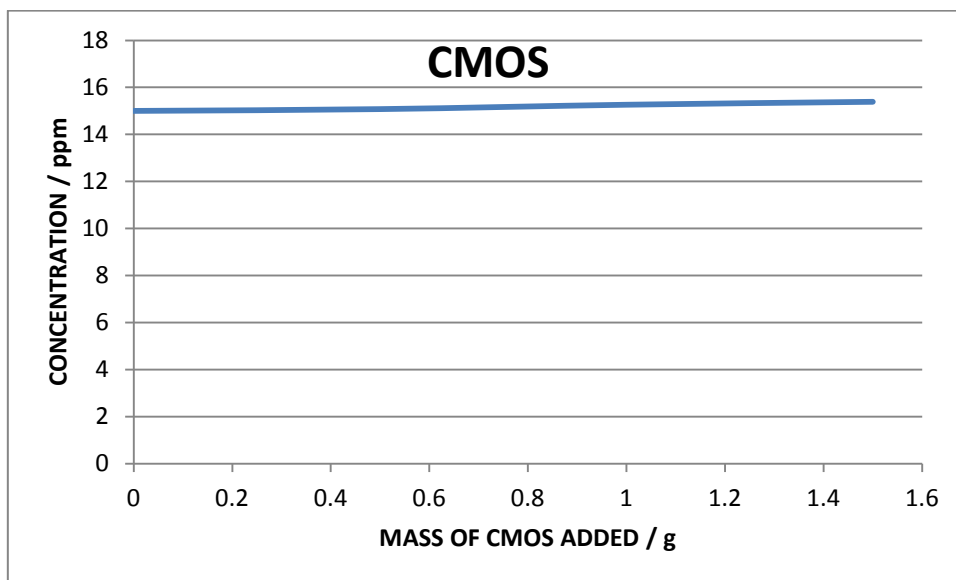


Figure 18: Effect of dosage of CMOS powders on removal of cadmium ions at initial cadmium concentration of 15 mg/L

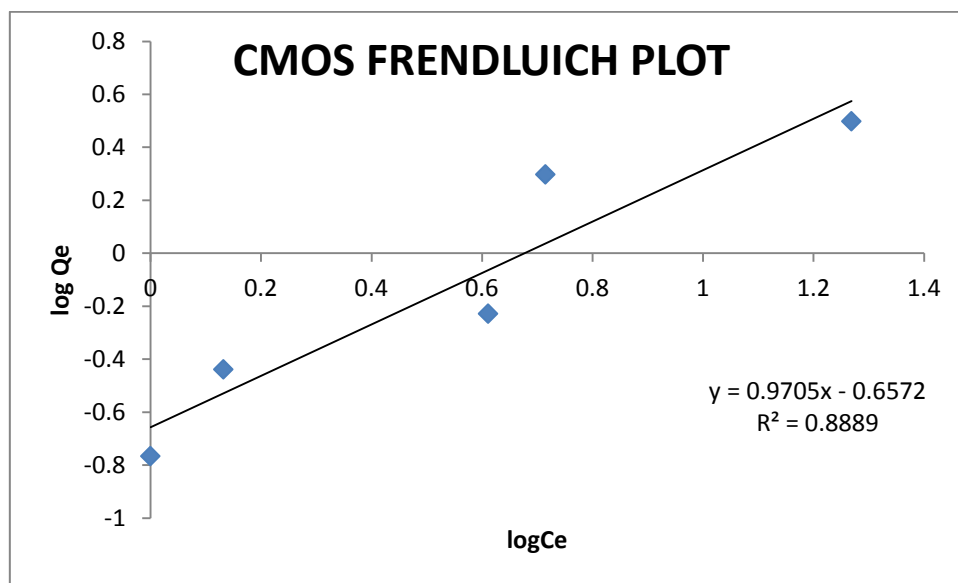
The MOS is thus a better than the CMOS since it increases its removal efficiency as the dosage is increased. MOS also has a more permanent removal of the Cd ions than CMOS. The interactions of the functional groups present in MOS may thus be said to be more powerful in binding Cd ions from solution than the adsorption of CMOS.

## Adsorption Isotherm Studies

### a) Chromium

MOS could not be explained by both langmuir and freundlich isotherms for the adsorption Cr. CMOS activity, on the other hand, can be explained by the freundlich isotherm, that is,

- $\log K_f =$  intercept (-0.6572), thus the adsorption capacity is  $10^{-0.6572} = 0.2202$  mg/g,
- and  $1/n =$  slope (0.9705g/L) thus the adsorption intensity is  $1/0.9705 = 1.0304$  L/g



**Figure 19: Freundlich adsorption isotherm of chromium ions on CMOS**

On average, a favorable adsorption tends to have Freundlich constant  $n$  between 1 and 10. (Febrianto et al., 2009) Therefore the adsorption of chromium by CMOS was favourable since  $n = 1.0304$ .

## b) Lead

MOS and CMOS showed results that could be explained by the Langmuir isotherm for lead as shown below in figures 20 and 21. Since the slope =  $1/Q_m$ , the langmuir constant for maximum metal uptake ( $Q_m$ ) was  $1/0.7808 = 1.281\text{mg/g}$  for MOS whilst that of CMOS was found to be  $1/1.8115 = 0.552\text{mg/g}$  for CMOS

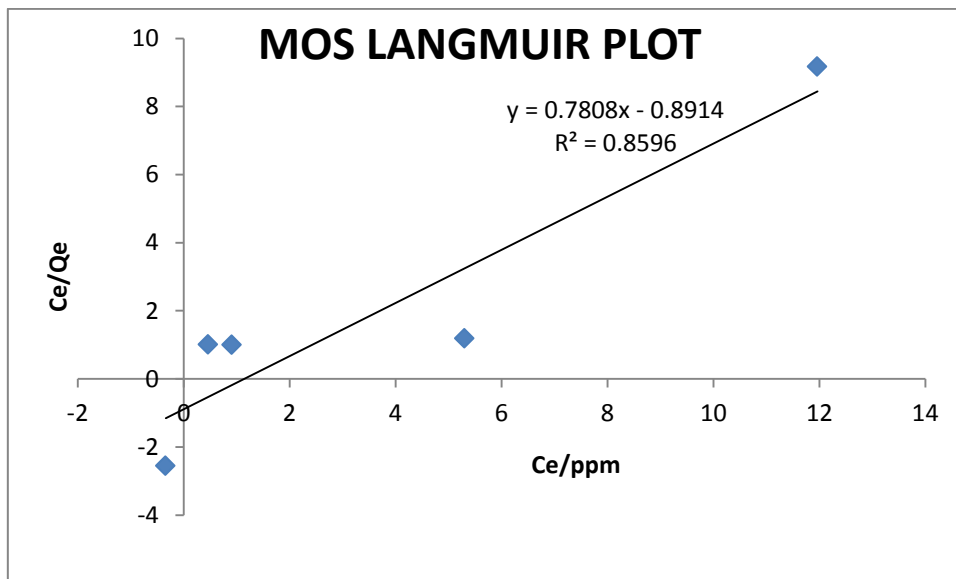


Figure 20: Langmuir adsorption isotherm of Pb ions on MOS

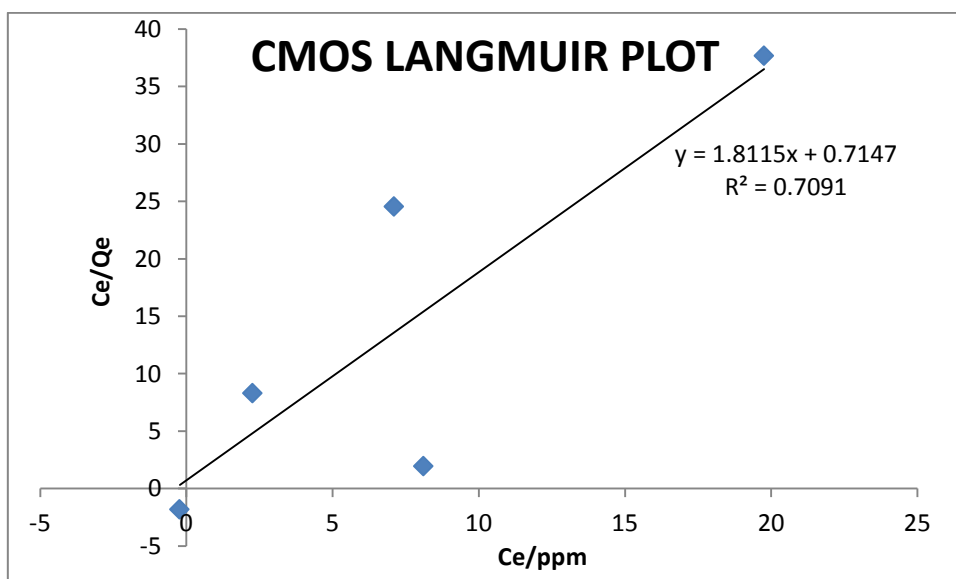


Figure 61: Langmuir adsorption isotherm of Pb ions on CMOS

However, both MOS and CMOS did not fit the freundlich isotherm model for lead.

### c) Cadmium

Results for Cadmium in figure 22, showed that they could be explained by the Langmuir isotherm with  $Q_m = 1/-5.9464 = -0.168\text{mg/g}$  for MOS

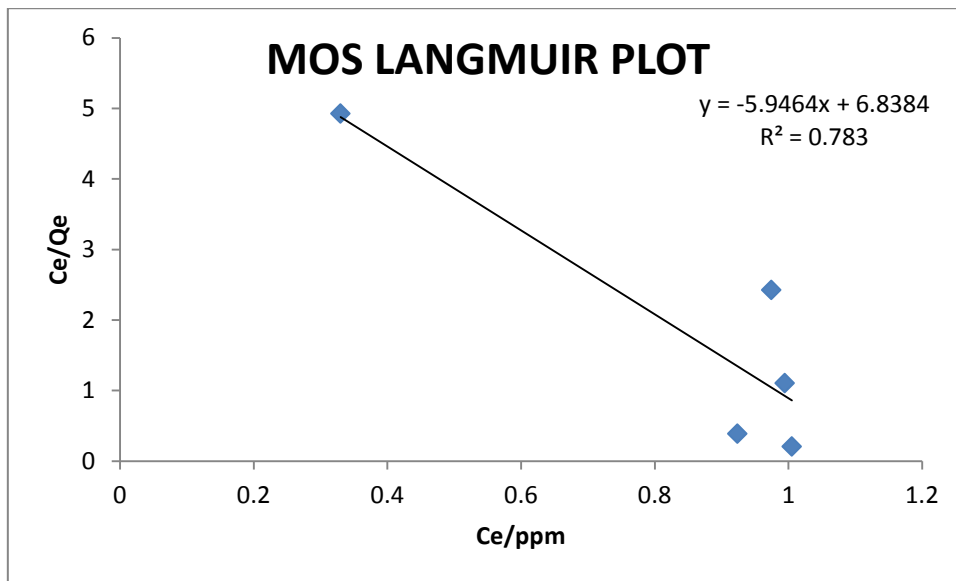


Figure 72: Langmuir adsorption isotherm of Cd ions on MOS

Cadmium could not be fitted in the freundlich isotherm.

## **CONCLUSION**

In the present study, batch adsorption experiments for the adsorption of Cr, Pb and Cd ions from aqueous solutions have been carried out using MOS and CMOS as adsorbent. The adsorption characteristics have been examined at different contact times, initial Cr, Pb and Cd ion concentrations, and different adsorbent dosage levels. In conclusion the study has shown that *MOS* and *CMOS* powder can be used for chromium, lead and cadmium ion removal from aqueous solution. The increase in initial chromium, lead and cadmium concentration results in a decrease of percent removal of the chromium, lead and cadmium. The equilibrium time for the adsorption of chromium, lead and cadmium by MOS and CMOS is 1 hr. The percent removal of chromium, lead and cadmium is increased with increase in the MOS and CMOS dosage up to 1.5 g of powder per 50 ml. The data for MOS fit well with Langmuir isotherm model for Lead and Cadmium whereas CMOS can be modelled by both Freundlich and Langmuir isotherms for chromium and Lead respectively. Overall, CMOS is a promising agent for removal of Chromium Lead and Cadmium ions from aqueous solution though it is not as effective as MOS. The effectiveness of CMOS can be enhanced by activation which will increase the surface area and porosity of the adsorbent.

## **RECOMMENDATIONS**

The CMOS adsorbent will need further characterization with respect to FT-IR, optimum pH and optimum particle size. Further study on the regeneration of the CMOS adsorbent will also need to be studied. Application to column analysis of the CMOS may also be explored as this will give a different dimension as compared to that of batch analysis.

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