

## REACTIONS OF COPPER AND CHROMIUM WITH EXTERNAL SURFACE OF WATER PIPELINES IN SOIL

Abdulfatah, A. Y.; Adedokun, T.A.; Umar, M. and Yunusa, G.H.

Geoenvironmental Research Group, Department of Civil Engineering, Bayero University, Kano

### ABSTRACT

*Water companies are facing problems of leakages and breakage of water pipelines that result into an increasing loss of water in the tune of Mega litres daily. Corrosion of metallic pipelines is one of the major causes of weakening the strength of water pipeline, which subsequently results into water leakage. In the wake of ever growing environmental pollution, this paper focuses on the reactions of soil contaminants; Copper (Cu) and Chromium (Cr) with external surface of buried water pipeline systems. Study of the behavior of the two metals in soil reveals that up to 7.852 mg/l of iron in solution was produced as a result of the pipeline's interaction with the two metals.*

**Keywords:** Pipeline Deterioration, Water Loss, Soil Contamination, Copper, Chromium.

### 1.0 INTRODUCTION

Soil environment is classified as the best final destiny for heavy metals and other environmental pollutants. Dissolved and particulate heavy metals have been reported in soil and sediments with huge concentrations from different parts of the world (Weng and Chen, 2000; Purohit *et al.*, 2001; Razo *et al.*, 2004). The same soils host majority of the pipelines used in different industries. These pipelines, mostly metal are widely used to transport raw and refined final products of the respective industries. Unfortunately, metallic pipelines are vulnerable to corrosion, leakages and breakage. The problem of pipeline failure is mostly attributed to the aggressiveness of the host soil environments as reviewed by (Abdulfatah *et al.*, 2006).

Corrosion of water distribution pipes is one of the main obstacles facing the water industry. A considerable development has been made in metallic corrosion protection; however the problem is still alarming. In 2005, the Water Services Regulatory Authority reported water loss in England and Wales in the year 2004-2005 to an approximate value of 3,600 Mega litres per day (OFWAT, 2005). Recent reports have also reported an annual monetary loss of hundreds of billions of Dollars in North America, United Kingdom, Australia and the rest of the world, due to water pipeline failure alone (Najjaran *et al.*,

2006). This problem costs the UK and other countries several billion Pounds (£) each year in preventative and corrective measures. The major cause of water pipeline failure is electrochemical corrosion (Galleher and Stift, 2004; Sadiq *et al.*, 2004), which further relates to the properties of the surrounding soil and bedding materials. Although several researches exist in the area of metallic corrosion in soil, it is not seemed to relate this corrosion to metals in soil, which are frequent contaminants of the soil. There has been a need to determine whether or not an accelerated level of heavy metals in soil has an effect on external corrosion of the water pipelines. Therefore, this research reports an investigative study carried out to assess the reactions of Copper and Chromium with external surface of Ductile Iron Water Pipeline buried in soil. Copper and Chromium are among the most frequent soil contaminants (USEPA, 2001; WHO, 2004) and the selection of Ductile Iron Pipeline was based on its predomination in water distribution in the water industry (Atkinson *et al.*, 2002; Doyle *et al.*, 2003; Rajani and Kleiner, 2003; Levlin, 2004).

## 2.0 EXPERIMENTAL METHOD

### 2.1 Parameters

Two Ductile Iron Pipe (DIP) sections were buried in a selected soil material in order to physically model their corrosion potential in contaminated soils. The modeling was done at Loughborough University with bedding and backfill materials conforming to international standards. The backfill soil was contaminated with known concentrations of Copper and Chromium at different stages of the experiments, which was then allowed to seep through the soil to the pipe sections using a controlled quantity of water representing three years' rainfall. The concentrations of these metals in the experiments were 26 mg/Kg-Cu and 84 mg/Kg-Cr, based on DETR Report (Carrington, 1998). A three year annual rainfall of Loughborough, 3 x 700 mm (UK Met office data) was used at each stage of the experiments.

### 2.2 Set-up

The experiments were set in a 1.8 x 1.5 x 1.5 m<sup>3</sup> metallic Soil Test Box. A 1.2 x 0.8 x 1.5 m<sup>3</sup> wooden box was constructed and placed in the metal box with its base and all the four side walls lined-up with a 5 mm PVC liner. This was done to exclude any possible contamination of results from the metallic box. Figure 1 shows the metallic soil box and the experimental dimensions used. A 6 mm mean size pea-gravel

was water-washed and used as the bedding material, with a back/side fill of Leighton Buzzard Silt-Sand of size range (0.004 to 0.4mm). The gravel and sand fell freely into place without requiring any sort of compaction. The system was excluded from external loading and a cover depth of 0.64 m was used.

### 2.3 Hydraulic Loading and Sampling

A rectangular irrigation module, sized 1.2 x 0.8 m<sup>2</sup> with 24 spray points was constructed and used on top of the test box. The module was fed from a laboratory tap ensuring an approximately uniform pressure upon the top soil. The total rainfall volume was distributed over a time span of 15 days with an irrigation rate of 0.5 litre/min. This rate gave a daily total of 120 litres for each stage of the experiments. Irrigation took place daily, with the box being drained before the next irrigation commenced. At each stage, a measured amount of one of the contaminants was dissolved in 1 litre of water and dosed upon the top soil, allowing a settlement period of one week before irrigation commenced. The whole system was isolated from the environment by using a water proof tarpaulin cover and the dimensions of the experimental set-up are shown in Figure 1. This ensured a mass balance of the contaminant and water to be carried out.

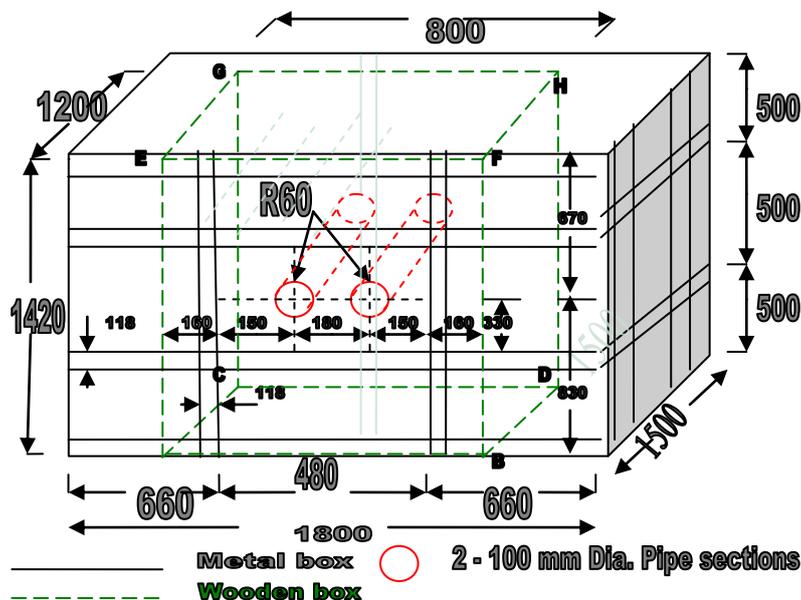


Figure 1: Metallic soil box

#### **2.4 Analysis of Metals**

All the collected samples were tested for soluble and total metal contents using an Inductively Coupled Plasma (ICP) machine. Water quality determinants, namely; temperature, pH, conductivity, redox potential, total dissolved solids (TDS), turbidity, inorganic carbon (IC) and total organic carbon (TOC) were also measured. The ICP machine was calibrated for primary and secondary linearity on each day of the analysis. The changes in Iron (Fe), Copper (Cu) and Chromium (Cr) contents are reported in this paper. Before the start of each analysis, the ICP machine was calibrated with mixed calibration solutions of the metals in test. The concentrations of the solutions prepared from stock solutions were 2.0, 4.0, 6.0, 8.0 & 10.0 part per million (ppm), which is equivalent to mg/l. A recovery coefficient of approximately 100% was obtained through satisfying the calibration process of the machine, in each case.

In the soluble metal analysis, crude samples were taken from the box, acidified with HNO<sub>3</sub> to a pH value less than 2 and preserved in a cold room. On each day of metal analysis, 100 ml of the crude samples were measured and filtered with No. 1- 185 mm dia. filter-papers before taking measurements. In the case of total metal analysis, 50 ml of the crude samples were measured and digested using the standard method of metal digestion with HNO<sub>3</sub> and HCL.

The digested samples (with all particulates dissolved) were also filtered with the same filter paper and final volumes raised to 100 ml by adding a least metal free (Reverse Osmosis) water. Final metal concentration in part per million (ppm) was determined by the following formula;

$$\text{Conc. (ppm)} = \text{Metal Content} \times \frac{\text{Final Volume}}{\text{Initial Volume}} \quad \dots$$

(1)

#### **2.5 Column Test**

A glass column experiment was set up with the same gravel and sand of the main experiment, at depth proportions of 1.33 to the main experiments. A corresponding three year rainfall (hydraulic loading rate) was passed through the column, and samples collected at the bottom of the column. The analyses carried out in the main box experiments were repeated on the column samples and the measured quantities were corrected by a change in depth factor of 1.33. The depth correction was made to ensure uniform equating for the test box and column systems.

### **3.0 EXPERIMENTAL RESULTS AND DISCUSSION**

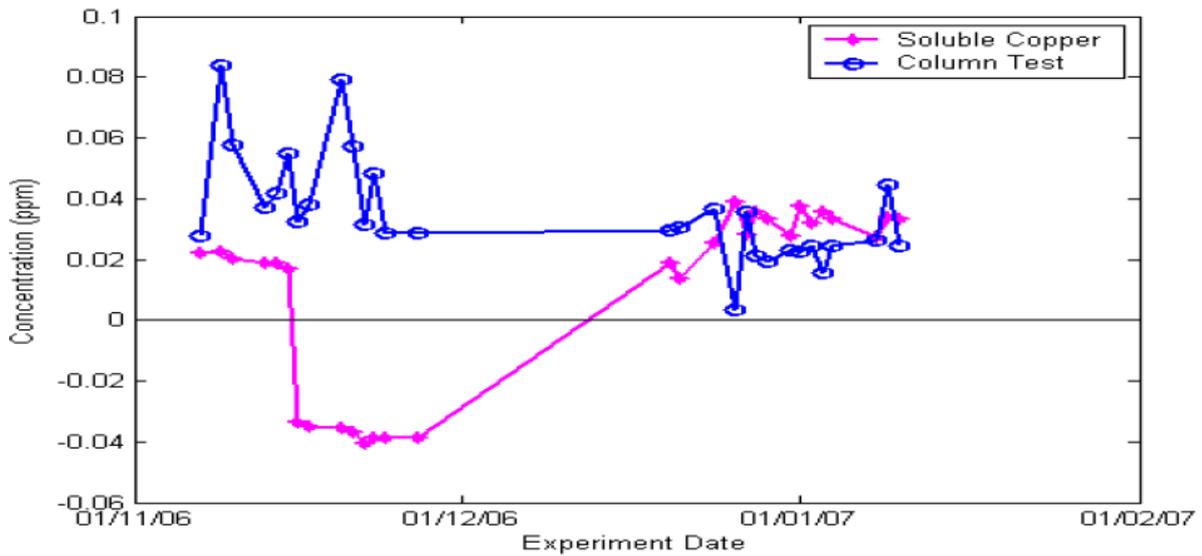
#### **3.1 Copper Content**

It can be seen from Figure 2 that Copper was initially detected with concentration 0.0223 ppm at the start of the experiment. Copper concentration suddenly went below the detection level of the ICP machine (which was 0.002 ppm) from point 7 through the end of the first experiment. The sudden decrease in Copper concentration brought about a suspicion that copper might have been absorbed by the gravel/sand or stuck on the pipe liner. At this point a column experiment was designed with acid-washed gravel through which a known concentration of Copper was flushed. On analysing the effluent sample, the results revealed a decrease in Copper content with an increase in Iron content (above tap water level of 0.03 ppm). This implies that the gravel absorbs Copper and releases Iron. This might be important with laying pipes on gravel. In this case, the contaminant went down to form a reservoir of Copper in the gravel pack. The idea of acid digestion on samples was considered to

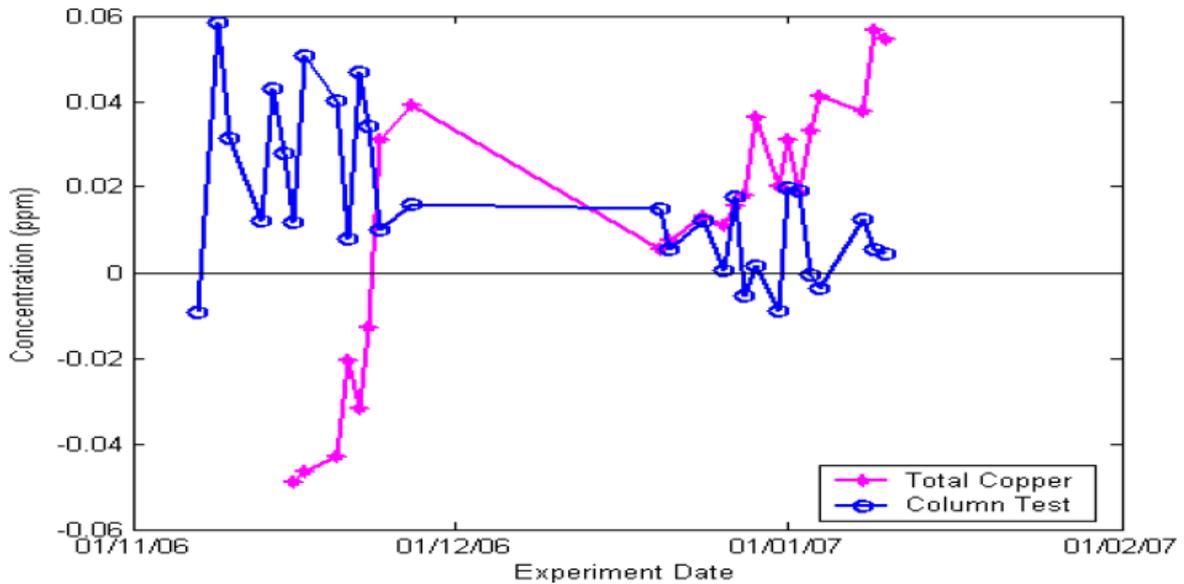
see whether dissolution and evaporation of particulates would expose more Copper in solution (total Copper). The total concentration of Copper in Figure 3 shows no change in the Copper value apart from the last two points that appeared within the detection limit of the ICP machine. The result of sand/gravel column test in the same figures shows all Copper values higher than the values from the main experiment. This was a confirmation of Copper adsorption in the main experiment and mostly because of nearly neutral pH that existed in the experiments. The dosing of Chromium shown by the second parts of the two figures shows significant amount of Copper in solution (above tap water value) at most of the points in the second experiment. This was likely to be an ion exchange reaction between Copper and Chromium on the surfaces of the sand and gravel. During the second experiment Copper reappeared in the samples with values exceeding the leached concentration from the column test.

In general, the behavior of Copper in this study agreed with (MacBride *et al.*, 1997; Sauve *et al.*, 2000) in which soluble Copper was best related to total Copper and organic matter content in

soil. Organic carbon was high at the start of the first experiment and later dipped to background level and it rose up again during the second experiment with Chromium.



**Figure 2: Soluble Copper Concentration**



**Figure 3: Total Copper Concentration**

There was a slight increase in pH from the beginning to the end of these experiments. The decrease in Copper value at the middle of the first experiment could also relate to an increase in pH. The range of pH values close to neutral in this experiment could be another explanation because Copper dissolves preferentially in lower pH values of about 5.5, (Martinez and Motto, 2000; Agbenin and Olojo, 2004).

**3.2 Chromium Content**

The ICP sensitivity for Chromium was 0.004 ppm and its tap water content was 0.002 ppm. It can be seen in Figure 4 that all but two values of Chromium were below the detection limit of the spectrometer. This indicates low Chromium in the tested samples in the first experiment before its dosing, as well as in the tap water used. There was



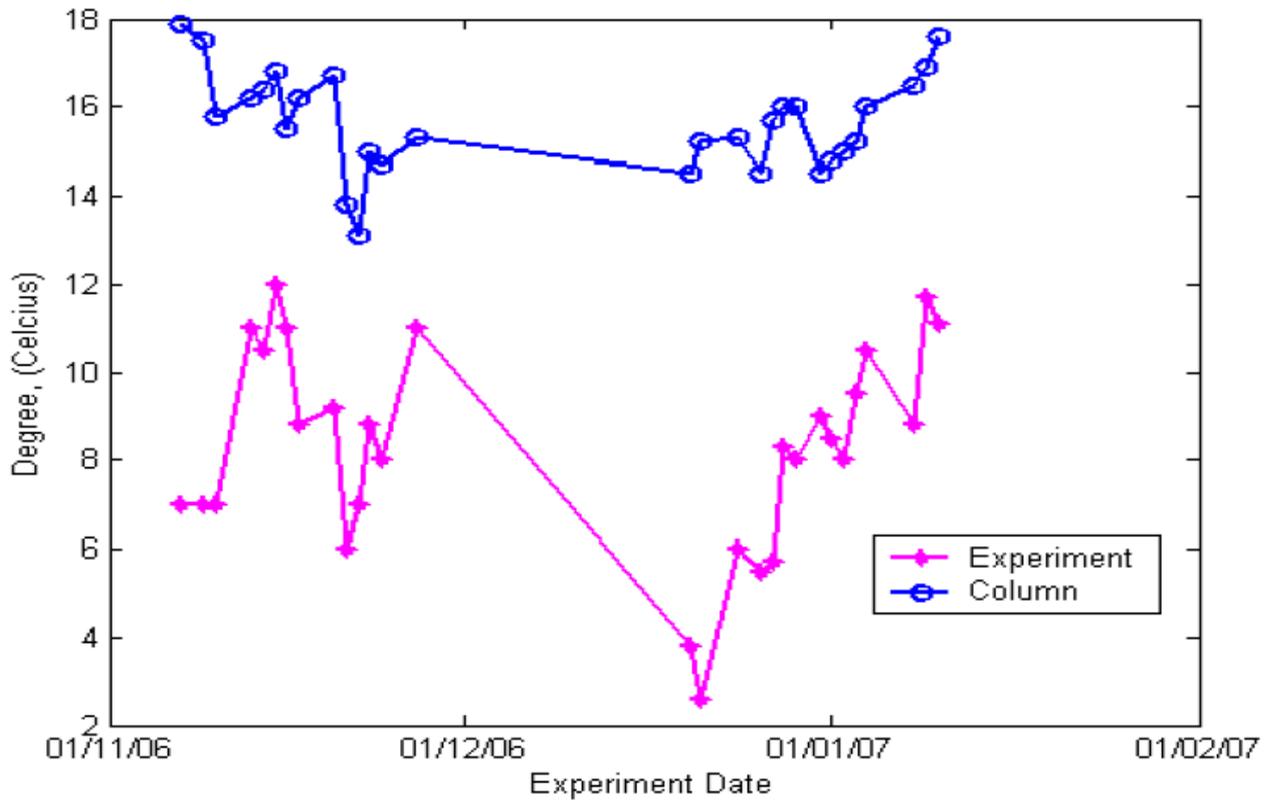




gradually to a value of 10 °C. These are typical of temperatures in the UK. The second experiment recorded a temperature of 4 °C at the beginning and then fluctuated between 3 °C and 12 °C throughout the second experiment.

Column experiment was conducted in the laboratory; as such the column curve shows laboratory room temperature ranging from 13 to 18 °C in the first experiment and 14.5 to 17.6 °C

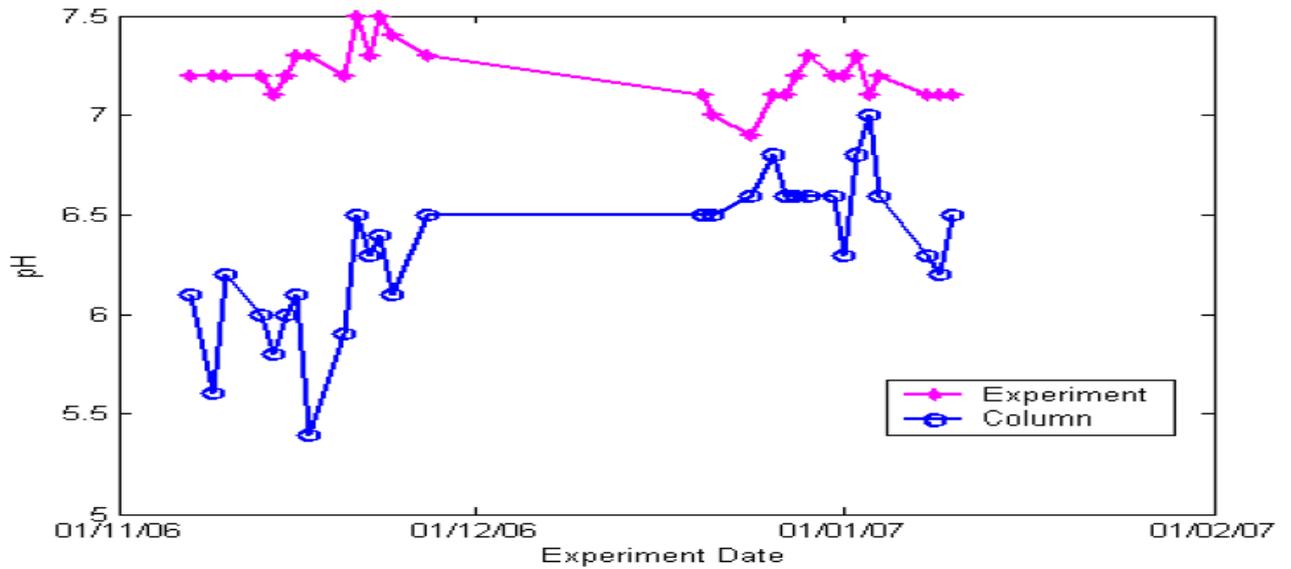
in the second experiment. Temperature influences corrosion through three principal factors namely; (a) the effect on the solubility of oxygen, (b) the effect on fluid viscosity in relation to hydrodynamic boundary layer and (c) the effect on diffusion coefficient. Higher temperature promotes soil activities that enhance more leaching from materials, hence this favoured leaching from the column.



**Figure 8: Temperature Readings**

Figure 9 shows pH values in the two experiments. pH value was mostly neutral ranging from 7.1 to 7.3 in the first experiment and from 6.9 to 7.3 in the second experiment. The column exhibited slightly lower pH values of 5.4 to 6.5 and 6.2 to 7.0 in the first and second experiments respectively. This was as a result of acid washing done on the gravel before its placement in the column. The two figures

indicate a slight inverse proportionality between temperature and pH. A study (Etchebers *et al.*, 2007) linked pH to weather conditions in which the pH varied inversely to temperature. A reason to this could be a reduction of biological activities in soil in low temperature. This could include the production of CO<sub>2</sub>, a weak acid in water that lowers soil pH condition.

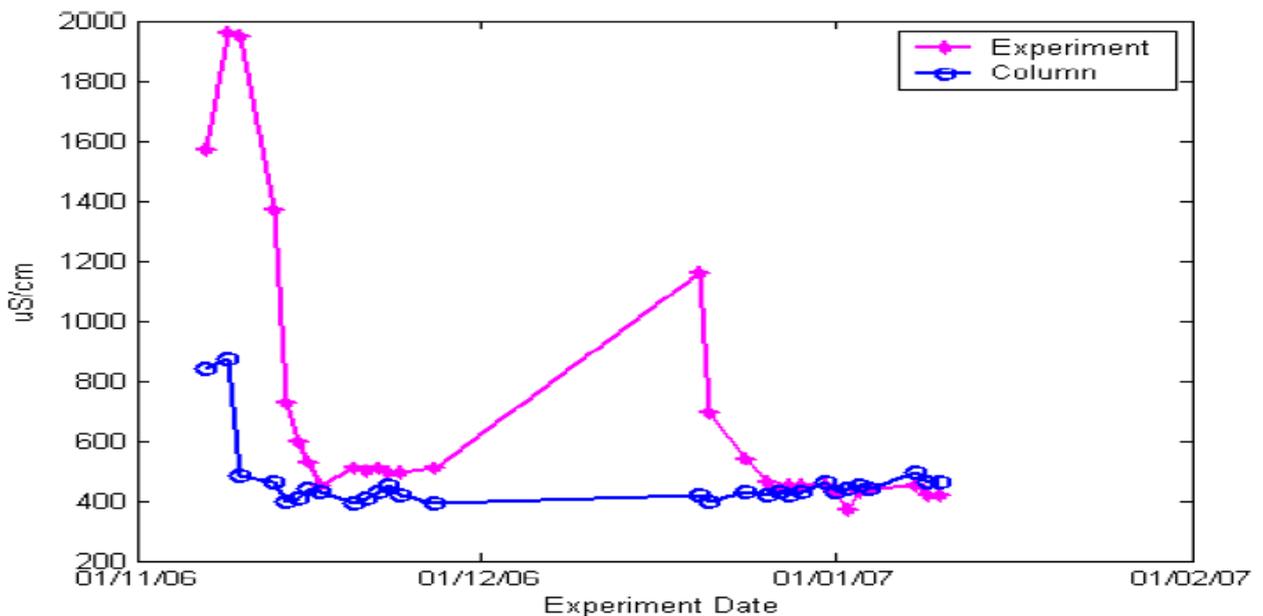


**Figure 9: pH Values**

**3.5 Electrical Conductivity**

Electrical conductivity is shown in Figure 10. Higher values of conductivity were recorded as 1950  $\mu\text{S}/\text{cm}$  at the start of the first experiment and 1160  $\mu\text{S}/\text{cm}$  at the beginning of the second experiment. These values dipped down considerably after few days of irrigation. The values later normalised close to a tap water value of 567  $\mu\text{S}/\text{cm}$ . The results of the column

experiment produced a similar curve to the main experiment but with lower values in the first as well as the second experiments. The difference in conductivity of 420 (860 minus 440)  $\mu\text{S}/\text{cm}$  in the column was due to sand/gravel washing at the beginning, whereas the peaks in the experiments could be related to contaminants loading.



**Figure 10: Electrical Conductivity**

The column results confirm that the significantly higher conductivity values at the beginning of the two experiments were due to contaminant loading. Soils with conductivity values greater than

500 $\mu\text{S}/\text{cm}$  are capable of promoting metallic corrosion. A safe range of soil resistivity was reported as 2000 to 5000  $\text{ohm cm}^{-1}$ , which is equivalent to 200 to 500  $\mu\text{S}/\text{cm}$ . On comparing the

total Iron curve in Figures 6 - 10, it was interesting to note that there was a decrease in total Iron concentration within the safe conductivity zone

(from the end of the first experiment down to the second experiment).

#### 4.0 CONCLUSIONS

The following conclusions were drawn from the presented results and these could relate to metallic corrosion. The total Iron concentration has shown a noticeable Iron enrichment in the first experiment, whose source could only be the pipe sections; the remaining fittings were not metallic. At the points of contaminant loading, there was an increasing occurrence of Iron content which later decreased with time (because of the contaminant flushing). Copper has shown a devastating effect despite its low dose in the experiments, which was not unconnected to the vast potential difference between Copper and Iron, in galvanic corrosion sense. Copper was absorbed to the pipe and gravel/sand. The level of soil contamination used was moderate in comparison with literature. An

increased level of contamination might further produce higher values of Iron in solution. The scope of the study was three years and the volume of rainfall used was low compared to other areas (with up to 5,000 mm/annum in the UK). A longer period with higher rainfall might also produce more leaching. The column experienced quicker water velocities and leached more Iron from the gravel/sand than from the box experiments. A more modified column design might reduce the level of Iron from the column and therefore increase the difference in Iron content between the main and column experiments. The huge differences in temperature and relative humidity between the box and column would have affected corrosion mechanisms in the two systems.

#### REFERENCES

1. Abdulfatah, A. Y., El-Hamalawi, A. and Wheatley, A. D. (2007). "Interaction between ductile iron water distribution system and heavy metal contaminated soils." Proceedings of conference, OttawaGeo2007, Canada, 1702-1708
2. Abdulfatah, A. Y., El-Hamalawi, A. and Wheatley, A. D. (2006). "Interactions between fluid carrying pipelines and their supporting soils" Proceedings of conference, ISEG/ICIDEN-ABUJA
3. Agbenin, J. O. and Olojo, L. A. (2004). "Competitive adsorption of copper and zinc by a Bt horizon of a savanna Alfisol as affected by pH and selective removal of hydrous oxides and organic matter" Geoderma, 119, 85-95.
4. Atkinson, K., Whiter, J. T., Smith, P. A. and Mulheron, M. (2002). "Failure of small diameter cast iron pipes." Urban Water, Vol. 4, 263-271.
5. Carrington, E. G., Davis, R. D. and Pike, E. B. (1998). "Review of the Scientific Evidence Relating to the Controls on the Agricultural Use of Sewage Sludge" Final report to the Department of the Environment, Transport and the Regions, Department of Health, Ministry of Agriculture, Fisheries and Food and the UK Water Industry Research Limited. Report No: DETR 4415/3
6. Doyle, G., Seica, M. V. and Grabinsky, M. W. F. (2003). "The role of soil in the external corrosion of cast iron water mains in Toronto, Canada." Canadian Geotechnical Journal, Vol. 40, 225-236.
7. Etchebers, O., Kedziorek, M. A. M. and Bourg, A. C. M. (2007). "Soil Water Chemistry as an indicator of the Reproducibility of Artificially Contaminated Soil Mesocosms" Water, Air and Soil Pollution, 179, 125-134.
8. Galleher, J. J. and Stift, M. T. (2004). "External Corrosion of Water System Piping-Causes and Solutions" Proceedings of conference, Pipelines International Conference, San Diego, California.
9. Levlin, E. (2004). "Water and Waste Pipes" Water Resources Engineering, Royal Institute of Technology, Web document 12-15
10. Martinez, C. E. and Motto, H. L. (2000). "Solubility of lead, zinc and copper added to mineral soils." Environmental Pollution, Vol. 107, 153-158.

11. McBride, M. Sauve, S. and Hendershot, W. (1997). "Solubility control of Cu, Zn, Cd and Pb in contaminated soils." European Journal of Soil Science, Vol. 48, 337-346.
12. Najjaran, H., Sadiq, R. and Rajani, B. (2006). "Fuzzy expert system to assess corrosion of cast/ductile iron pipes from backfill properties." Computer-Aided Civil and Infrastructure Engineering, 12, 67-77.
13. Purohit, K. K., Mukherjee, P. K., Khanna, P. P., Saini, N. K. and Rathi, M. S (2001). "Heavy metal distribution and environmental status of Doon Valley soils, Outer Himalaya, India." Environmental Geology, 40(6), 716-724.
14. Rajani, B. and Kleiner, Y. (2003). "Protection of ductile iron water mains: what protection method works best for what soil condition?" Journal of American Water Works Association, Vol. 95, issue 11, 110-125.
15. Razo, I., Carrizales, L., Castro, J., Diaz-Barriga, F. and Monroy, M. (2004). "Arsenic and Heavy Metal Pollution in Soil, Water and Sediments in a Semi-Arid Climate Mining Area in Mexico" Water, Air and Soil Pollution, Vol. 152, 129-152.
16. Sadiq, R., Rajani, B. and Kleiner, Y. (2004). "Probabilistic risk analysis of corrosion associated failures in cast iron water mains." Reliability Engineering and System Safety, Vol. 86, 1-10.
17. Sauve, S., Hendershot, W. and Allen, H. E. (2000) "Solid Solution partitioning of metals in contaminated soils: Dependence on pH, total metal burden and organic matter." Environmental Science and Technology, 34, 1125-1131.
18. Weng, H. and Chen, X. (2000). "Impact of polluted canal water on adjacent soil and groundwater systems." Environmental Geology, 39(8), 945-950.

