THE STUDY OF CORROSION BEHAVIOUR OF CU IN SOME COMMERCIAL BEVERAGES BY CHEMICAL AND ELECTROCHEMICAL MEASUREMENT

Xiaonan Wang[1], Bev Christian[1] and Mark Pritzgker[2]

BlackBerry[1], Cambridge, Ontario, Canada
Department of Chemical Engineer, University of Waterloo[2]
Waterloo, Ontario, Canada nwang@blackberry.com

ABSTRACT:
The corrosion behaviour of pure copper in 16 selected commercial beverages was studied. Experiments were also conducted in the presence of citric and phosphoric acids to investigate their role in the corrosion process in these beverages. Two experimental approaches were used to investigate the corrosion behavior: a chemical method in which the dissolved metal concentration was measured after immersion of a sample in a beverage and an electrochemical method using the Tafel extrapolation technique. The metal surfaces were also examined by SEM/EDX after the immersion tests and electrochemical polarization.

Among the important conclusions from this research are that the order in which the various beverages affect the corrosion rate as evaluated by Tafel extrapolation of the polarization curves did not agree with the order based on measurement of the dissolved metal concentration as determined by the immersion tests. Second, the ranking of the beverages according to their ability to dissolve copper based on shortterm immersion tests (1 day) did not agree with that based on long-term tests (~5 or 7 days). These discrepancies likely stem from the complicated dynamics of the corrosion of metal and the various physical, chemical and electrochemical processes that take place in these beverages. No simple correlation was found between the beverage properties and composition and the dissolved copper concentrations after immersion, whether based on shortterm or long-term tests. However, the corrosion rate of copper in the 7 soft drinks as determined by the Tafel extrapolation method was found to depend on the pH, but not in other beverages such as juices, hot drinks, milk and alcohol. SEM examination of copper surfaces showed that they corroded uniformly in all test beverages. Evidence for the formation of corrosion products containing chlorine was found in both the immersion test and the polarization scan when the applied potential increased to 1.0 V above the open-circuit potential. Of the beverages considered in this study, Gatorade was consistently found to be the most corrosive for copper.

Key words: copper, beverages, corrosion.

INTRODUCTION:
Copper has the second highest electrical conductivity of any element after silver and so is widely used for various purposes in the electronics industry. A typical PCB consists of a copper connection path integrated in a fiberglass reinforced epoxy polymer.

In the electronics industry, one of the most common reasons for failure of devices is metal corrosion. Numerous research reports related to metal corrosion behaviour have been published [1]. Metal corrosion is usually a very complex phenomenon. Different types of corrosion can occur simultaneously in the same media and under the same environmental conditions. Corrosion is affected by many factors that are related to the environment and to the metal. However, corrosion mechanisms and behavior are often difficult to explain because the various processes and factors can be difficult to sort out and the theoretical foundations are sometimes insufficient to provide a satisfactory answer [2].

A metal is most likely to corrode when it is contact with an aqueous solution. Some works dealing with the effect of the acidic, neutral and alkaline media on the corrosion of copper are found in the literature [3-6]. However, the effect of different beverages on the corrosion behavior of copper has not been reported in the literature. The aim of the present work is to perform a systematic study of the effect of 16 common commercial beverages on the corrosion behavior of the copper. A set of methods was used to carry out chemical analysis of the beverages including anion, cation and organic acid determination. The corrosion behaviour of the test metal was investigated by measuring the amount of dissolved metal and conducting electrochemical experiments such as open-circuit potential measurements and linear potential scans.

MATERIALS AND METHOD
All chemicals were reagent grade acquired from the following sources: citric acid (EMD Chemical Inc, Belgium), DL-malic acid (Mallinckrodt Baker Inc, Canada), phosphoric acid (Fisher Scientific, USA) and NaCl (EMD Chemical Inc, USA).

The 16 beverages selected for investigation were commercial soft drinks, milk, juices and alcohol products purchased at local grocery stores. Prior to testing, all carbonated beverages were degassed in an ultrasound bath for 5 to 10 minutes until completely de-carbonated. For hot chocolate and tea, a bag of hot chocolate (28g) was dissolved in 175 ml hot water, and

one bag of tea was immersed in 180 mL hot water for three minutes.

Table 1 The pH and conductivity values in 16 common beverages.

16 common beverages	pH	Conductivity(µs/cm)
Coca-Cola	2.47	1255
Pepsi	2.48	1124
Canada Dry	2.82	598
Dr. Pepper™	2.86	657
Gatorade	2.92	2200
Sprite	3.26	499
Wine	3.46	2445
Apple Juice	3.57	2375
Orange Juice	3.80	4295
Beer	3.98	1497
Tomato Juice	4.00	15060
Root Beer	4.24	433
Red Rose Orange Pekoe Tea	5.33	506
Master Coffee	6.04	2555
2% Partly Skimmed Milk	6.63	5210
Hot Chocolate	7.01	4760

Master coffee™ was prepared directly from a coffee machine. All tests and measurements were carried out on beverages once cooled down to room temperature. The pH value and electrical conductivity of the 16 beverage were measured and listed in Table 1.

Inorganic anions, cations and organic acids of the 16 commercial beverages selected were also analyzed using a *Dionex* Ion Chromatograph, *Agilent Technologies* HPLCMS system and a *Perkin Elmer 3000DV* Inductively Coupled Plasma Optical Emission Spectroscopy (ICPOES).The resulting analyses are displayed in Table 2, 3 and 4.

Copper was ordered from EMD Chemical Inc with over 99.9% purity. Metal foils were cut into pieces with dimensions that were approximately 80mm±2mm in length and 25±2mm in width and 0.05 mm thickness metal strips for the immersion tests. To remove any potential contaminant, all metal strips were rinsed in DI water in the ultrasound water bath for 5 minutes, then degreased by acetone and IPA in the ultrasound water bath for 5 minutes, respectively, finally washed by DI water and dried in the air before use in the dissolution experiment.All metal samples for electrochemical corrosion behavior investigation were cut into circles with 1.4 cm diameter. Specimens were

installed in an electrode tip with an exposed test area of 0.785 cm^2.The methods chosen for study of corrosion behaviour of metals were electrochemical and nonelectrochemical techniques. The non-electrochemical method was carried out by measuring metal ion concentration in the test solution as a function of time to study metal corrosion behaviour. Each cleaned strip of metal was inserted into a tube with 50 ml of a single beverage. These strips were fully immersed in the test beverages. Three samples were run for each beverage. All samples were kept in the oven at 40ºC±2ºC for the specified amount of time (24 hours, 72hours, 120 and 168 hours). After the designated amount of time, the samples were removed from the oven. Strips were taken out from test solutions. 2% (vol) nitric acid was added and shake in order to preserve the sample and ensure that all metal components were in dissolved ionic form. All sample solutions were diluted 10 and 100 times using Milli-Q water before they were analyzed by the ICP-OES. Dissolved copper metal ion concentrations in 16 commercial beverages are expressed as µg/l (ppm). The selected analytical wavelength of copper was 324.7 nm.

The electrochemical methods chosen were (1) open-circuit potential (OCP) measurements and (2) linear potential scan experiments. A conventional three-electrode cell was used for the electrochemical experiments.1.4 cm diameter flat circular samples were prepared for the electrochemical corrosion testing. Prior to tests, these prepared samples were degreased with acetone and alcohol and ultrasonically washed with deionized water for 5 minutes. Each sample was mounted in an electrode tip holder with a 0.785 cm^2 exposed area. Two parallel Pt rods were utilized as counter electrodes and Ag/AgCl/3M KCl was a reference electrode. All potentials reported herein correspond to the Ag/AgCl scale. All experiments were conducted at room temperature using a *PGSTAT302 Autolab Metrohm* equipment. 150 ml test solution was used in each case.

Table 2 Concentration of inorganic ions in 16 commercial beverages.

	P	F-	Cl-	SO_{42}	NO_{3-}	NO_{2-}
Pepsi	53	12.7	17.4	29.2		
Dr. Pepper	47	12.2	19.2	32.3		
Coke	67	14.8	32.9	41.4		
Sprite		6.8	14.3	21.9		
Root beer		17.6	30.1	25.2	3.1	
C.Dry			34.6	27.3		
Gatorade	41		456			

Apple J	19	199	1251	107		
Orange J	40	69	601	84		
Tomato J	23		3373	140		
Beer	22	97.0	85.6	638		98.4
Wine	85	398	260	310	7.1	933
Tea	14	21.5	13.8	12.1	2.5	
Coffee	29	148.	106.8	20.5		
H.C	33	49.9	863.5	28.2		
Milk	13		991	86.5		

Table 3 Analysis results for metal cation (µg/mL)

	Calcium	Iron	Potassium	Magnesium	Sodium
Pepsi	1.55	NA	24.2	0.253	2.85
Dr. Pepper	1.68	NA	2.17	0.302	42.8
Coca-Cola	12.5	1.06	1.29	2.98	16.2
Sprite	17.2	NA	1.23	4.25	86.3
Root beer	15.8	156	1.5	4.09	92.7
Canada Dry	26.1	NA	36.8	12.9	41.3
Gatorade	2.45	0.58	149	0.886	458
Apple J	55.1	0.737	1120	42.9	27.6
Orange J	83.2	0.54	1630	110	5.03
Tomato J	42.1	9.94	2590	96.6	2120
Beer	88.6	NA	303	76.4	24.3
Wine	70.5	2.46	943	130	37
Tea	0.464	NA	112	6.24	8.27
Coffee	94.2	NA	854	36.2	117
Hot chocolate	22.1	0.019	901	25.7	669
Milk	716	NA	994	69.8	266

	lactic	succinic	malic	tartaric	citric	benzonic	fumaric	acetic	ascorbic	phosphoric
Pepsi	0	0	0	0	55	0	0	0	0	532
Dr. Pepper	0	0	0	0	0	253	0	0	0	459
Coca-Cola	0	0	0	0	0	0	0	0	0	509
Sprite	0	0	0	0	1135	61	0	0	0	0
Root beer	0	0	0	0	152	502	0	0	0	0
Canada Dry	0	0	0	0	1234	190	0	0	0	0
Gatorade	0	0	0	0	3289	0	0	0	0	367
Apple J	42	6.7	4125	0	53	0	0	220	11.8	242
Orange J	121	6.1	2135	0	7415	0	0	82	0	364
Tomato J	77	4.6	480	0	2964	0	0	0	8.3	304
Beer	81	143	143	0	150	0	1.8	56	0	160
Wine	1080	1023	35.4	1345	46	0	0	563	15.4	954
Tea	0	0	22.6	0	0	0	0	0	0	17
Coffee	108	3.6	104	0	329	0	3.8	299	0	342
Hot chocolate	161	5.7	18.7	0	335	0	0	112	0	479
Milk	0	0	18.4	0	1270	0	0	0	0	1662

Table 4 Concentration of some organic acids and phosphoric acid (µg/mL)

The open-circuit potential E_{corr} was monitored for 3 hours. The open-circuit potential of the metal electrode was measured in a test solution until a steady state value was attained. After steady state was reached, a linear potential sweep in the anodic direction was performed at a scan rate of 1 mV/s, starting from 0.25 V below the OCP and terminating at 0.25V above the OCP. The output from these experiments yielded a polarization curve showing the current response obtained versus the applied potential. At the completion of the

corrosion experiments, the specimens were dried in air prior to examination of their surfaces. For examination of the metal surfaces, an optical microscope and JEOL JSM-6460LV scanning electron microscope (SEM) at 20KV with energy dispersive X-ray analysis (EDXA) attachment were used.

RESULTS AND DISCUSSION:

Tests involving the immersion of copper samples in the beverages for 1, 3, 5 and 7 days at 40 ℃ in the oven were carried out in triplicate. The concentrations obtained in the 16 beverages are listed in Table 5, while plots showing the effect of immersion time on the average dissolved concentration are presented in Figures 1-3. It was found that the variation of dissolved copper concentration with time follows two types of behaviour depending on the beverage. Figures 1 and 2 shows those cases where the dissolved copper concentrations rises slowly at the outset before increasing more quickly after about 3 days of immersion and finally leveling off after about 5 days. This behaviour is observed in all of the test beverages except hot chocolate, coffee and apple juice. As shown in Figure 3, the dissolved Cu concentration increases only

days but then rises rapidly thereafter when copper is slightly during the first 5 An important conclusion that can be drawn from these immersion experiments is that the longer

term corrosion rates in some of the beverages are not well predicted on the basis of short term 1-day immersion tests. This is due to the fact that their corrosion rates vary significantly over the course of the immersion time. The average corrosion rates can be estimated from the slopes of the curves in Figures 13. Figure 4 shows the variation in the corrosion rates (expressed in units of mg/cm^2 ·day) obtained over the immersion period for all of the beverages. With a few exceptions, the dissolution rates are quite variable, both rising and falling at different times. It is interesting to note that apple juice is the only beverage in which the rate increases monotonically.

The dissolved copper concentrations after 1, 3, 5 and 7 days of immersion are plotted versus the beverage pH in Figure 5 in order to determine whether a correlation exists between these quantities. Although a few outliers exist (i.e., Gatorade, tea and root beer), a decrease in the beverage pH leads to a rise in the dissolved copper concentration. Although not included here, no strong correlation between the copper concentration and the beverage conductivity or titratable acidity was found. The effect of pH was investigated more

immersed in hot chocolate, coffee and apple juice. closely by measuring the corrosion of copper after 3 days immersion in a
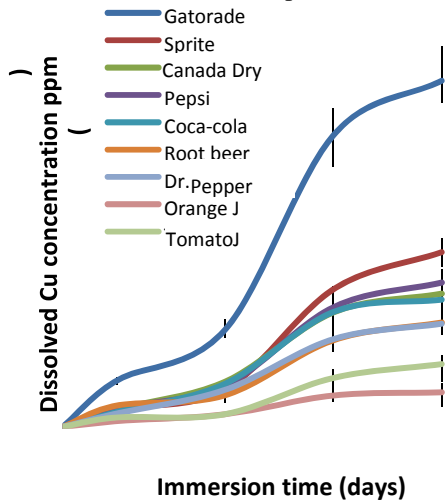

Figure 1 Dissolved copper concentration as a function of the immersion times in 7 soft drinks and orange J and Tomato J.
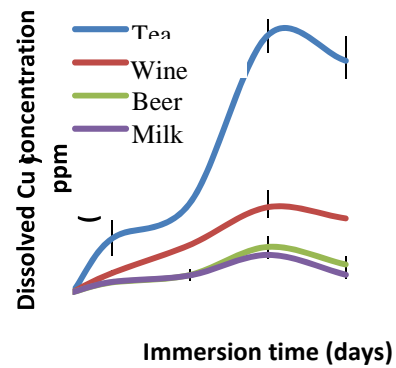

Figure 2 Dissolved Cu concentration as a function of the immersion time in wine, beer, milk and tea.
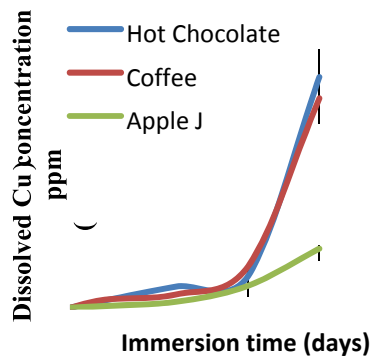
Figure 3 Dissolved copper concentration as a function of the immersion times in coffee, hot chocolate and Apple J.

synthetic solution containing 500 ppm NaCl, 500 ppm citric acid and 500 ppm phosphoric acid, which are the main ingredients in many of the beverages. NaOH was added to adjust the pH value without changing any of the other components. As shown in Figure 6, the corrosion rate of copper was found to decrease as the pH rises from 2 to 4, but then stabilizes with a further pH increase from 4 to 6. This suggests that the dissolution behaviour in this solution differs at pH below 4 from that above pH 4. Again, a similar trend is observed when copper is immersed in the beverages (Figure 5). This supports the idea that H^+ plays a significant role in copper corrosion. However, two notable exceptions to the general trend with respect to pH are tea and root beer in which much more copper dissolution than would be expected based on their pH alone is observed. It is not obvious from the chemical compositions of tea and root beer as to why they are outliers (Table 2). Tea stands out among the beverages in this study by containing a very low level of each of H^+, citric acid, phosphoric acid and Cl^-. Similarly, the concentration of each of these components in root beer is also relatively low.

constituents can play an important role in copper
Thus, it is likely that other ions (Table 2) and other organic acids (Table 4) in these beverages shows that they do not contain unusually low or high levels of these species except perhaps 502 ppm benzoic acid in root beer. It is possible that some other component(s) not analyzed in this study contributes significantly to copper corrosion. Further research on this topic is warranted.

Another implication of the results in this synthetic solution and from the beverages themselves is that a complex interaction between some of the constituents likely occurs during copper dissolution. In order to investigate this aspect further, a series of experiments were conducted to examine the effect of citric acid concentration in a synthetic solution in the presence and absence of NaCl. Figure 7 compares the effect of citric acid on the corrosion rate when 500 ppm NaCl is present and when none has been added. The addition of NaCl has a significant effect and more than doubles the corrosion of the copper. It is also interesting to note that the corrosion rate becomes essentially independent of the citric acid concentration above about 1000 ppm regardless whether or not NaCl is present.

The effects of citric, ortho-phosphoric and malic acids alone at concentrations of 1000, 2000 and 5000 ppm on the

dissolution of copper were evaluated in separate experiments. The dissolved copper concentrations after three days of immersion in each of the three acids are listed in Table 6.These data are shown graphically in Figure 8. Each of these acids appears to have a different effect on copper corrosion. The amount of copper that dissolves does not depend on the citric acid concentration between 1000 ppm to 5000 ppm, consistent with the results in Figure 7. On the other hand, phosphoric acid appears to increase the corrosion rate, although the effect is not dramatic. Malic acid appears to have a more complicated effect by enhancing the corrosion rate as its concentration increases up to about 2000 ppm, but then having the opposite effect if any more is added. However, given the wide range of acid concentrations used in these experiments, the effects evident in Figure 8 are not large and certainly smaller than the range of solubilities obtained after 3 days immersion in the commercial beverages (Table 6). Thus, it is difficult to assess the individual roles of each of these components on copper corrosion when present together with all the other components in the test beverages.

SEM examination of the Cu surfaces after the immersion test showed that uniform corrosion occurred in all of the drinks. dissolution. Examination of the composition of inorganic Representative SEM images and EDX spectra in Pepsi (phosphoric acid-rich), Canada Dry (citric acid-rich) and Gatorade (rich in both phosphoric acid and citric acid) are shown in Figures 9-11. The copper surface remains relatively clean after immersion in Pepsi and Canada Dry with no evidence of any insoluble film found on the copper surface. The image of the metal after immersion in Gatorade shows the presence of crystals over its surface (Figure 11). EDX analysis of the crystals reveals that they contain chlorine and copper with only trace amounts of carbon and oxygen, indicating that they consist of some sort of copper chloride compound.

Table 6 Dissolved Cu concentration (ppm) after 3 days immersion test in different acid solutions.

Acid concentration (ppm)	Copper concentration after 3 days immersion (ppm)		
	Citric acid	Phosphoric acid	Malic acid
1000	163	192	206
2000	162	206	235
5000	162	220	179

Table 5 Dissolved Cu concentration (µg/L) after 1, 3, 5nd 7 days of immersion to the test beverages.

	1 day	3 days	5 days	7 days

Apple J	1.5±0.04	4.9±1.13	17.9±7.84	48.3±9.36
Hot chocolate	6.0±0.87	17.3±0.53	25.8±6.14	188.0±20.95
Coffee	6.6±0.23	10.9±1.71	33.6±2.47	170.7±32.39
Beer	14.5±2.02	25.7±1.46	68.1±16.89	41.6±10.29
Milk	15.2±0.35	25.1±8.57	56.0±34.76	26.1±10.83
Orange J	20.1±2.69	43.8±0.64	109.3±24.44	120.1±46.00
Wine	28.4±3.50	71.1±0.68	128.3±22.50	111.3±1.15
Tomato J	32.5±4.00	44.0±2.00	170.0±32.60	218.0±52.89
Dr. Pepper	46.5±5.74	129.0±11.14	305.0±127.43	359.3±31.79
Coke	52.2±3.72	150.0±7.00	400.0±30.81	443.0±27.62
Canada Dry	61.5±10.97	157.5±3.54	398.7±11.59	464.0±68.79
Sprite	62.1±3.38	129.0±19.08	479.3±16.17	608.3±69.30
Pepsi	64.4±5.13	143.0±17.06	416.3±65.61	446.3±107.83
Root beer	74.0±8.67	109.9±29.98	301.3±24.50	404.3±42.55
Tea	80.6±26.98	134.0±4.00	388.3±25.54	349.7±33.56
Gatorade	161.3±12.90	338.3±32.32	1,015.0±103.32	1,205.3±105.51

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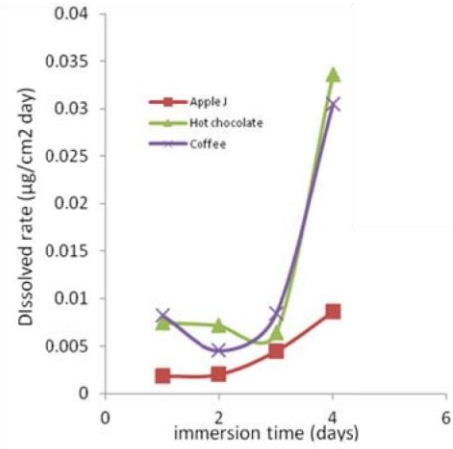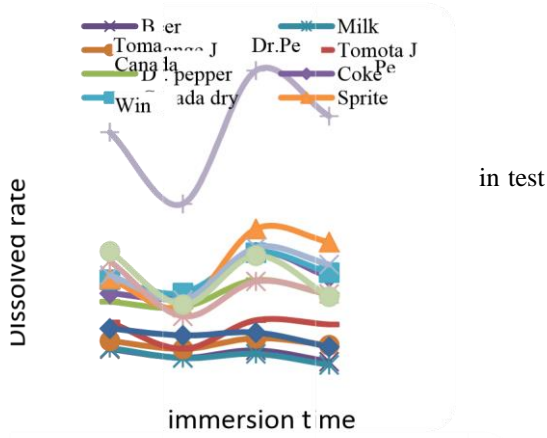
Figure 4 dissolution rate of copper as a function of the immersion time beverages.
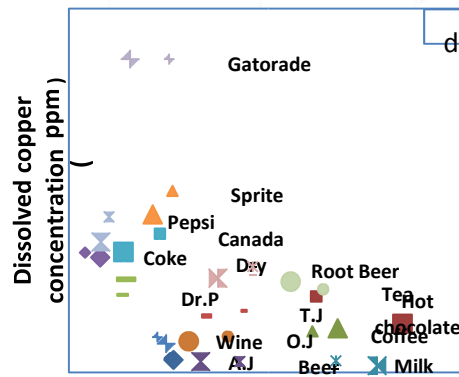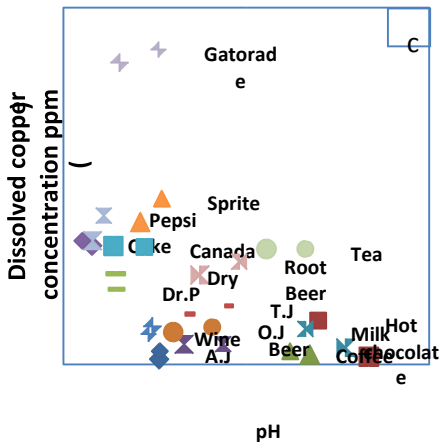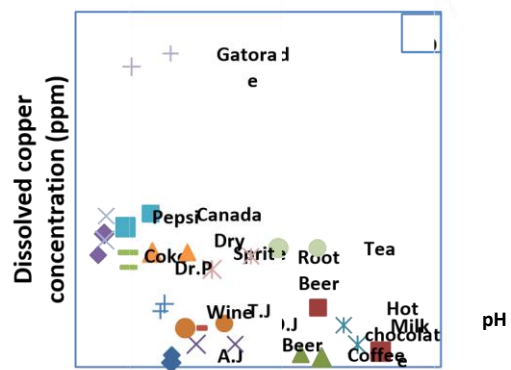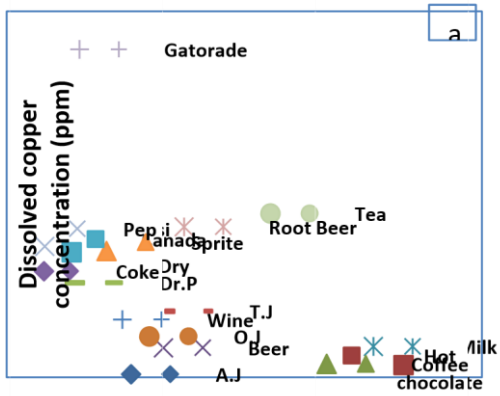

Figure 5 Dissolved copper concentration after immersion of (a) 1 (b) 3 (c) 5 and (d) 7 days as a function of the beverage pH.
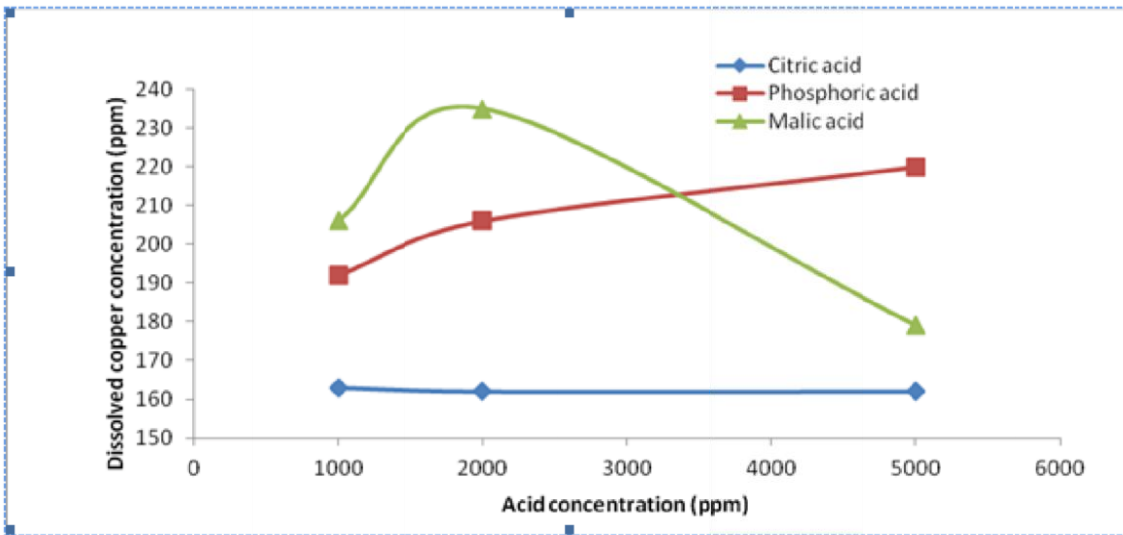
Figure 8 plots of dissolved copper concentration as a function of acid concentrations.
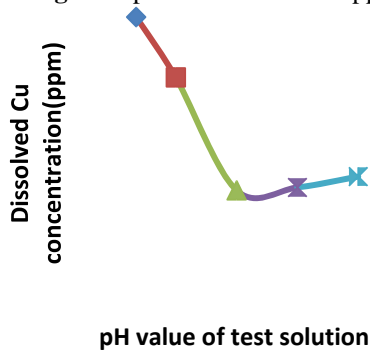

Figure 6 Effect of pH on dissolved copper concentration in solutions containing 500 ppm NaCl, 500 ppm citric acid and 500 ppm phosphoric acid.
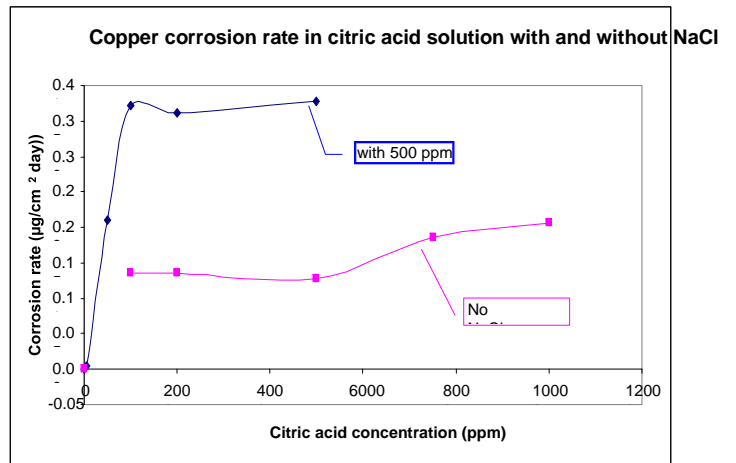

Figure 7 Effect of citric acid on copper corrosion rate ($\mu g\ cm^{-2}$ day) in the absence and presence of 500 ppm NaCl.

The potentials of copper electrodes were recorded as a function of time for 3 hours in 16 commercial beverages

under open-circuit conditions. The resulting plots are presented in Figure 12. In most of the test beverages, the OCP values only vary slightly in the active direction over the 3-hour period. The most notable exceptions to this trend are observed when copper is immersed in tomato juice and the two alcohol-containing beverages – beer and wine. In these cases, the OCP decreases significantly (by over 200 mV) before steady state are reached. This suggests that a surface oxide film may have formed during the immersion period in these beverages [7]. Copper electrodes more or less branches were used for the determination of the corrosion parameters in these beverages. The corrosion parameters obtained are listed in Table 7. The entries are listed in order of decreasing corrosion rate for convenience. The data in Table 7 indicate that the corrosion rate of copper in the soft reached a steady state in all test beverages within 3 hours. After the steady-

state potential value was reached, the potential was scanned from –250 mV to +250 mV with respect to the open-circuit potential at a sweep rate of 1 mV/sec and the resulting current response was measured. Replicate experiments were conducted for each beverage to ensure that the polarization curves obtained were reproducible. The corrosion current densities of copper in the various beverages were determined by fitting the ButlerVolmer equation to the experimental data using the NOVA software. A linear Tafel portion in the anodic regions was observed. Consequently, only the data on the anodic drinks tends to decrease with an increase in pH. In other beverages such as juices, hot drinks, milk and alcohol, the corrosion rate is independent of the pH value. No significant correlation between corrosion potential and rate was observed.
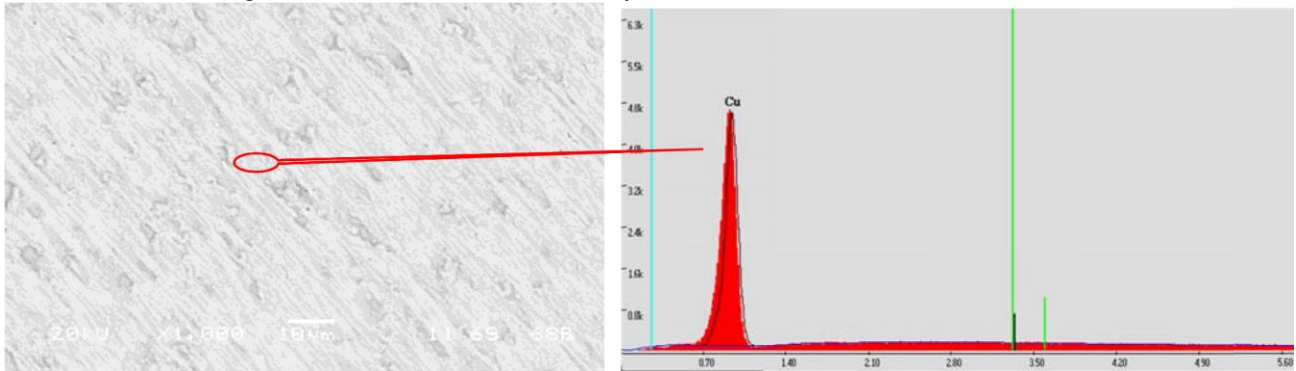

Figure 9 SEM image of copper at 1000X after 5 days immersion test in Canada Dry and EDX spectrum of the indicated region on surface.
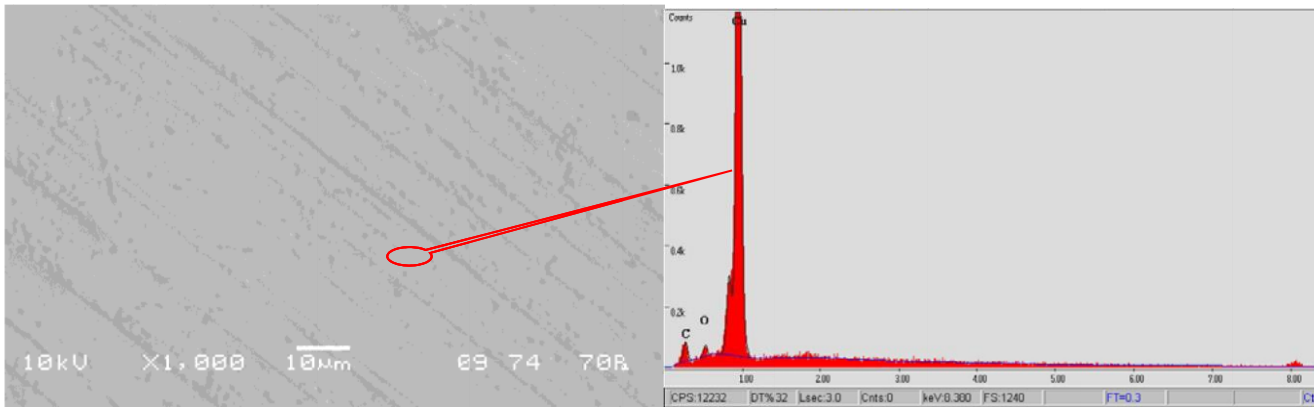
Figure 10 SEM image of copper at 1000X after 5 days immersion test in Pepsi and EDX spectrum of the indicated region on surface.
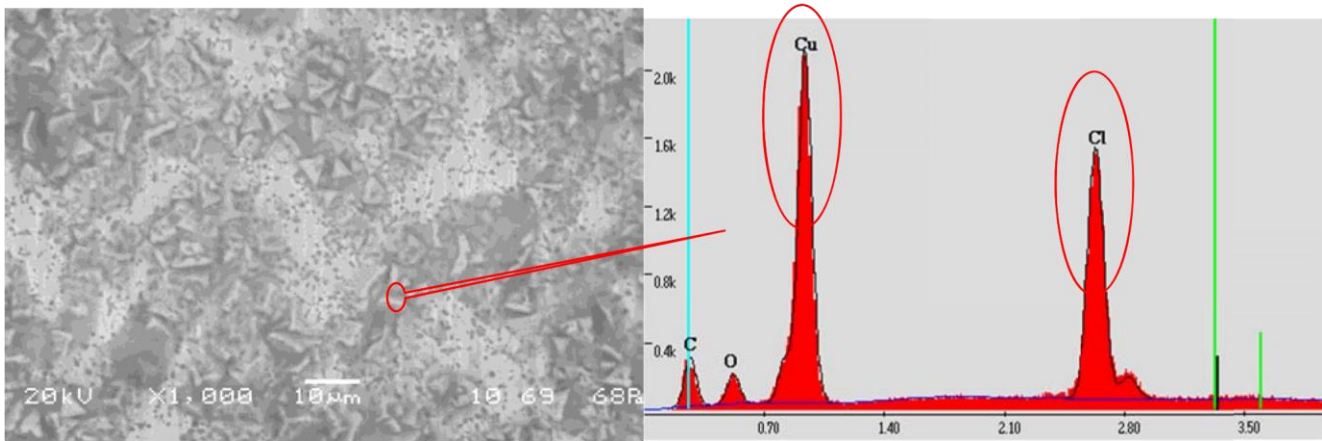

Figure 11 SEM image of copper at 1000X after 5 days immersion test in Gatorade and EDX spectrum of the indicated region on surface.
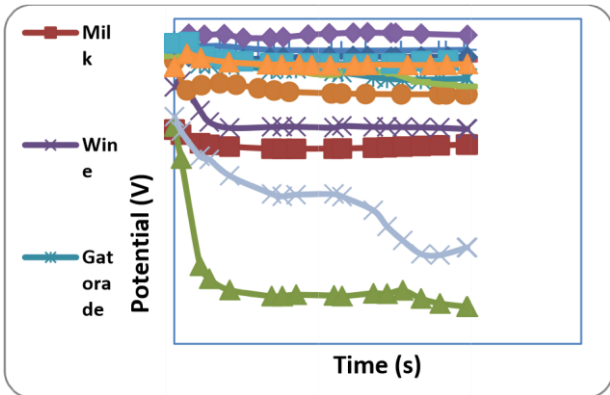

Figure 12 Variation of the open-circuit potential over time measured for copper electrodes immersed in some of the beverages.

SEM examination of the copper electrodes after the anodic scans were complete showed that uniform attack occurred in all of the test drinks. Representative SEM images and EDX spectra after anodic scans in Pepsi and Gatorade are shown in Figures 13 and 14, respectively. The SEM image and EDX spectrum of the sample exposed to Pepsi is relatively clean and displays only small carbon, oxygen peaks in addition to those of copper which is very typical of the SEM images and EDX spectra obtained for copper immersed in the other beverages.

An SEM image and EDX analysis of a copper sample that had been immersed in Gatorade which contains extremely high Cl^- levels reveals the presence of significant amounts of chlorine on the electrode surface (Figure 13). This observation is consistent with the SEM images and EDX analysis obtained after copper was immersed in Gatorade for 5 days (Figure 11).

Table 7 Corrosion parameters of pure copper in the test beverages with their pH values.

| Beverages	Corrosion rate (mm/year)	Polarization resistance (O)	Ecorr (mV)	jcorr (mA/cm²)	pH
Coke	0.44	28	12	3.80E-02	2.47
Pepsi	0.44	58	11	3.80E-02	2.48
Canada Dry	0.28	41	-0.63	2.40E-02	2.82
Dr.pepper	0.28	81	49	2.40E-02	2.86
Gatorade	0.18	93	-72	1.50E-02	2.92
Sprite	0.099	300	-8.1	8.50E-03	3.26
Root Beer	0.0089	7300	-190	7.60E-04	4.24
Tomato J	0.11	28000	-440	9.00E-03	4
Orange J	0.0062	3800	-74	5.40E-04	3.86
Apple J	0.0027	160000	-81	2.30E-04	3.57
Beer	0.021	1500	-330	1.80E-03	3.98
Wine	0.0065	6200	-110	5.60E-04	3.46
Milk	0.018	650	-140	1.50E-03	6.63
Hot Chocolate	0.007	9200	160	6.00E-04	7.01
Tea	0.004	370000	230	3.40E-04	5.33
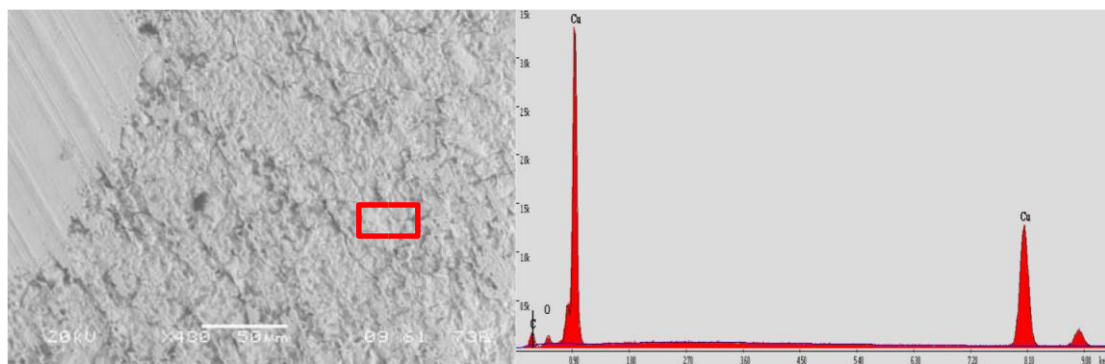
Figure 13 SEM image of Cu electrode after anodic polarization while immersed in Pepsi and EDX spectrum of the indicated rectangular region on surface.
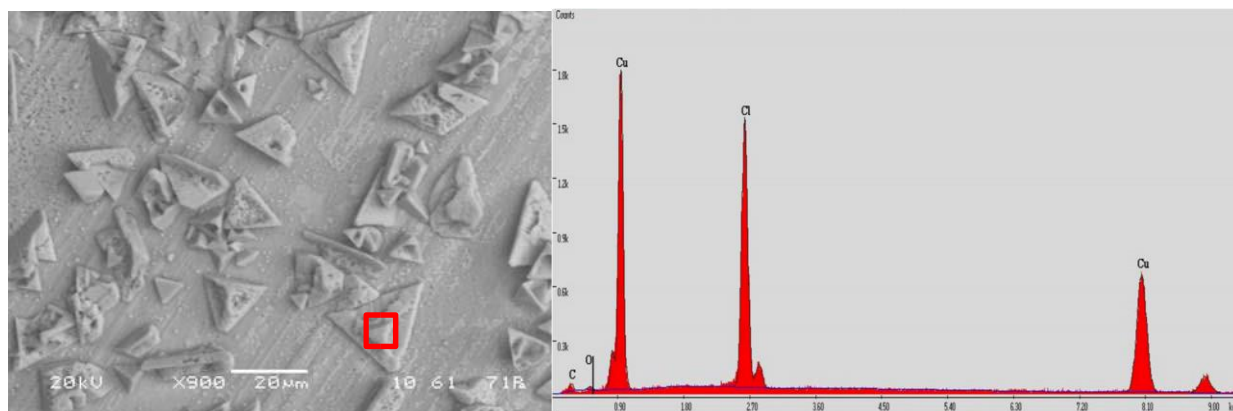

Figure 14 image of Cu electrode after anodic polarization while immersed in Gatorade and EDX spectrum of the indicated rectangular region on surface.

CONCLUSION:

The corrosion behaviour of copper has been studied in 16 commercial beverages by measuring the dissolved metal concentration after immersion for different durations using ICP-OES and by using a number of electrochemical techniques (OCP measurement, Tafel extrapolation methods). Physical properties and chemical composition of 16 commercial beverages were also investigated by a set of efficient methods. The metal surfaces after corrosion were examined and characterized by SEM/EDX analysis. The following conclusions can be drawn from the above experiments:

1.The ranking of the beverages according to their ability to dissolve copper based on short-term immersion tests (1 day) did not agree with that based on long-term tests (~5 or 7 days). No correlation was found between the dissolved copper concentrations and beverage properties (e.g. pH, conductivity, etc.) or composition regardless whether shortor long-term immersion tests were conducted.

2.The ranking of corrosion rates of Cu estimated from the polarization curves is not in agreement with that based on the measurement of dissolved Cu concentrations after immersion in the various beverages for either short- or longterm.

3.The electrochemical measurements indicated that the corrosion rates depend on pH in the 7 soft drinks, but not in other beverages such as juices, hot drinks, milk and alcohol.

4.NaCl promotes the corrosion of copper in citric acidcontaining solutions.

5.SEM examination of copper surfaces showed that they corroded uniformly in all test beverages.

6.The immersion tests show that Gatorade is the most aggressive beverage toward copper. Evidence for the formation of corrosion products containing chlorine was found in both immersion test and the polarization scan.

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