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# Kitchen Sink Wastewater (KSWW) Treatment Using Batch Electrochemical Coagulation (BECC)

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**Abstract**
*In this research, electrochemical coagulation (ECC) is used as a treatment technique for the removal of target parameters COD & TDS from the grey water. Grey water used in BECC was collected from a nearby high load restaurant. BECC using SS electrodes and combination of SS and Cu electrodes were carried out to remove target parameters like COD and TDS from wastewaters. Effects of operating parameters like initial pH, applied cell potential and current on the performance of ECC process were investigated. Optimum COD and TDS removal efficiencies of 80% and 20% were achieved for BECC of KSWW using combination of SS and Cu electrodes under optimized operating conditions. The overall COD and TDS removal efficiencies of 95.45% and 6.37% were achieved for BECC of KSWW using SS electrodes under optimized operating conditions. Optimal operating costs were found to be 0.25 and 0.40 US \$/m³. Specific energy consumption at various optimal operating conditions for BECC of KSWW using combination of SS and Cu electrodes and only six SS electrodes were estimated to be 44 and 40 kWh/m³ respectively.*

**Keywords**
*Grey water, electrochemical coagulation, kitchen sink wastewater, COD and TDS*

## I. Introduction

Water demand is increasing with the uncontrolled increase in population and rapid growing urbanization. Reduction in its non potable uses or good wastewater treatment facilities are the only options must be considered. Centralized treatment facilities are hard to implement in developing countries because of high investment, operation and maintenance costs, ripple geography and large quantity of potable water used for conveying the wastes to the centralized systems [1].

There is a growth in demand for new wastewater treatment technologies as the world's population increases and depletion/ contamination of fresh water resources. Wastewater treatment technologies used in municipal applications require further development in order to reduce the pollution of the water bodies.

Grey water can be used untreated, or it can be competently treated to various degrees to decrease risks related to nutrients and disease causing microorganisms relying on intent of end-use. The suitable makes use of grey water depend upon each the source of grey water and the level of treatment.

A wide spectrum of applied technologies, from very simple to complicated systems, will also be utilized for grey water treatment and reuse.

Conventional treatment technologies such as TF, filtration, RBC, SBR and MBR were practiced for grey water till date. The studies on grey water often fascinated by treatment with a number of technologies to an extent, which satisfy various points of reuse or recycle standards as good because the optimization of treatment efficiency [3].

In the present day, ECC is seen as advanced alternative treatment compared to other conventional methods in pollutant/ contaminant removal from domestic/ industrial wastewaters. In this novel technology, metal cations are released into water through dissolving metal electrodes by way of power supply. Simultaneously, beneficial side reactions separate flocculated material from water. Contrastingly, adverse side reactions may also occur like: deposition of salts on the electrode surface, which may cause deterioration in the of removal efficiency after long period of operation.

Pollutants in raw KSWW wastewaters are typically colloidal and suspended solids, which cannot be easily removed by simple coagulation, filtration, sedimentation or flotation due to their stable electrostatic repulsions between particles.

## II. ECC Mechanism

ECC uses an ECR to treat polluted water. Sacrificial anodes corrode to release active coagulant cation, usually aluminium or iron, to solution. Accompanying electrochemical reactions are dependent on species present and usually evolve electrolytic gases. The coagulant's delivery and its nature influence the coagulation and separation processes by its speciation, removal path and associated by-product, electrolytic gases. The mechanism involved in batch ECC process is schematically shown in Fig. 1.

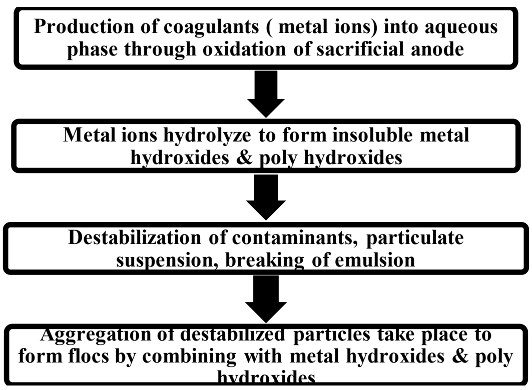


**Fig. 1 ECC mechanism**

The chemical reactions taking place at the anode and cathode are given as follows:

At the anode: $M (s) \rightarrow M (aq) n^{+} + ne^{-}$

$2H_2O \rightarrow 4H^{+} + O_2 + 4e^{-}$

At the cathode: $M (aq) n^{+} + ne^{-} \rightarrow M(s)$

$2H_2O + 2e^{-} \rightarrow H_2 (g) + 2OH^{-}$

M represents the material used as electrode and n is the number of electrons.

### III. Materials and methods

Grey water refers to the wastewater generated from kitchens, laundries and bathrooms, except from toilet flushing, bidets and urinals typically has a lower pathogen content and organic matter load than combined household wastewater which is contaminated with human excreta and urine [2].
Grey water generally represents up to 70 % of total used water but contains only 30% of organic fraction and from 9% to 20% of the nutrients. The composition, characteristics and volume of grey water dependent on the lifestyles, standard of living, water use, economic status and consumer choices [8].

#### 1. Grey water sampling

Grey water sample used in this investigation was KSWW. Grab samples of KSWW was collected as and when required for BECC experiments from a nearby high load restaurant located in Mysuru, Karnataka, India.

#### 2. Experimental setup and procedure

All BECC experiments were carried out at laboratory scale using batch electrochemical reactors made of plexiglas material. SS and Cu electrodes of thickness 0.9 mm were procured and arranged in parallel with a bipolar configuration. Operating parameters such as electrolyze time, electrode material, stirring speed and electrode spacing were maintained at desired levels throughout all the BECC experiments. The circuit closes, the moment the DC power supply switch is on. The bulk content of the ECR was stirred using an induction magnetic stirrer by introducing a magnetic bead in to the ECR. During electrolysis, samples were retrieved from the reactor at every 20 min, filtered and analyzed for parameters pH, COD and TDS.
The experimental setup of ECR is shown in Fig. 2.

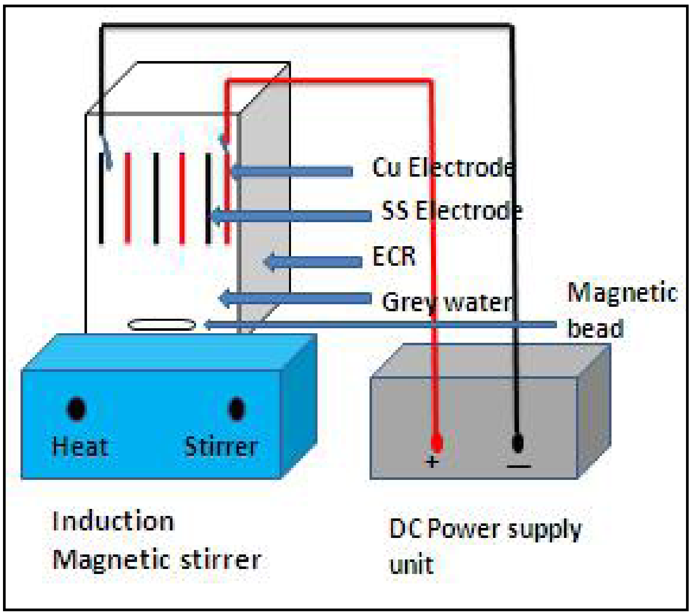


Fig. 2 : Experimental setup of BECC of KSWW

Raw kitchens sink wastewater without any dilution, as is, was treated using ECC in a batch ECR for various SA/Vs. The combination of Cu and SS electrodes were arranged with an inter-electrode spacing of 1 cm. The Cu electrode was connected to the positive terminal, while the SS plate was linked to the negative terminal of the DC power supply. Three ECRs of different volumes ranged 1, 2 and 3L were used in different experiments.

### IV. Results and discussions

Wastewaters generated from restaurants not only differ by volume but also display change in characteristics. Thus, it is very difficult to have a single generalized characterization for restaurant waste streams. Every time, the wastewater samples were obtained, each sample showed different characteristics for various parameters [4]. A value band obtained after characterization of KSWW for various physico-chemical parameters is shown in Table 1.

Table 1 : Physico-chemical characteristics of KSWW

| No | Parameters | Description/Value |
|---|---|---|
| 1 | pH | 8.70 – 8.90 |
| 2 | Colour | Brownish yellow |
| 3 | TS (mg/L) | 2662 - 2682 |
| 4 | TSS (mg/L) | 490 - 610 |
| 5 | TDS (mg/L) | 2076 - 2172 |
| 6 | Chlorides (mg/L) | 480 - 507 |
| 7 | Conductivity (μS/cm) | 2988 - 3016 |
| 8 | Total Alkalinity (mg/L as $CaCO_3$) | 508 - 562 |
| 9 | COD (mg/L) | 900 - 1600 |
| 10 | $BOD_5$ (mg/L) | 120 - 331 |
| 11 | Nitrates (mg/L) | 16.3 – 17.7 |
| 12 | Phosphates (mg/L) | 84.5 – 86.5 |
| 13 | Oil & Grease (mg/L) | 482 - 904 |

By observing Table 1, the initial pH of raw kitchen sink wastewater is in the alkaline range. Raw restaurant wastewater is seen as a brownish yellow in colour because of the presence of organic matter, cleansing and dish washing solvents and food preparing ingredients. Higher values of TDS, chlorides and Oil and grease may be observed from the characteristics. Phosphate values are rather high because of the presence of alkaline cleansing and dish washing solvents. COD values for the grab samples ranged from 900 – 1600 mg/L. COD to BOD ratios were of the order of 5 – 7.5 showing recalcitrant condition of the wastewater.

#### 1. Batch ECC treatment of raw KSWW for different SA/Vs: 17, 25, and 50 m2/m3 with SS and Cu electrode combinations.

Batch ECC experiments were carried out at laboratory scale for the treatment of KSWW without dilution using batch ECRs having effective volumes of 1, 2 and 3L respectively with SS and Cu electrode combinations.
While using 1L capacity ECR, the operating conditions maintained were: 6E: SS & Cu; E-spacing: 1 cm; agitation: 350 rpm; cell voltage: 30 V; current: 1.1 A; ET: 120 min; $pH_0$: 5.09; $COD_0$: 4964 mg/L; $TDS_0$: 2906 mg/L. While using 2L and 3L capacity ECR, all the operating parameters were same as for 1L ECR except agitation speed of 250 rpm.

Fig. 3 shows change in COD values during BECC at different ET for KSWW without dilution for different SA/Vs and polarity.

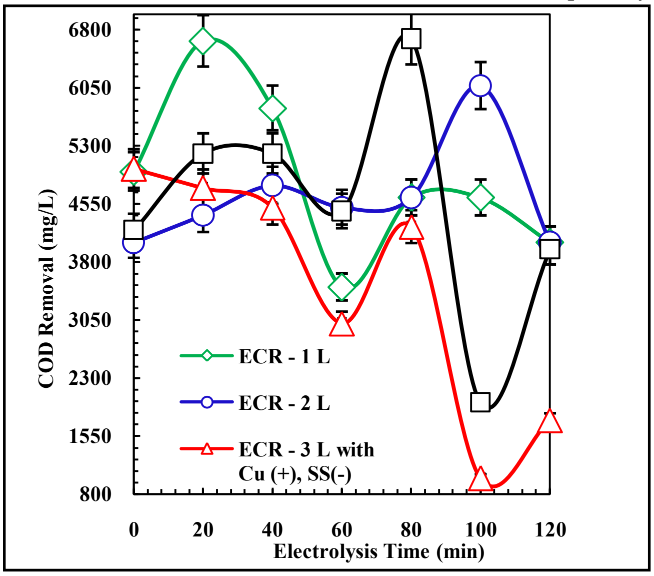


Fig. 3 COD degradation curve for KSWW without dilution for different SA/V

Operating conditions: ECR: 1L - agitation: 350 rpm; ECR: 2 & 3L - agitation: 250 rpm; 6E: SS & Cu; E-spacing: 1 cm; cell voltage: 30 V; current: 1.0 A; ET: 120 min & $COD_0$: 4205 mg/L – 5000 mg/L.

For 1L ECR, after 15 min ET, an increase in the COD value from 4964 mg/L to 6650 mg/L was observed; reasons being a higher dissolution of electrodes at the beginning of the EC process. However, at 120 min ET, COD removal efficiency of 60% was observed. Low removal of COD is because of recalcitrance and refractory nature of wastewater, and a wide variety of alkali chemicals present, which hinder the ECC process.

For 2L ECR, an increase in COD values up to 100 min ET was observed. The ET seemed insufficient and also the volume of the ECR as well.

In case of 3L ECR, an initial decrease in COD values was observed from the $COD_0$: 5000 mg/L to 3000 mg/L up to 60 min ET. A significant decrease in COD value from 4250 mg/L to 1000 mg/L was observed at 100 min ET with 80% COD removal efficiency, after which a slight increase was

observed at $ET_{max}$ 120 min ET showing 65% COD removal.

For 3L ECR with Cu (-) and SS (+), change in COD values was observed from COD0: 4205 mg/L to 4452 mg/L at 60 min ET. However, after 60 min ET, the COD degradation curve observed was similar to the 3L ECR with reversed polarity discussed above. Low COD removal ascribed to less metal hydroxides formation and a corresponding increase in the TDS content are the focus issues.

Fig. 4 shows change in TDS values during ECC at different ET for KSWW without dilution for different SA/Vs and polarity.

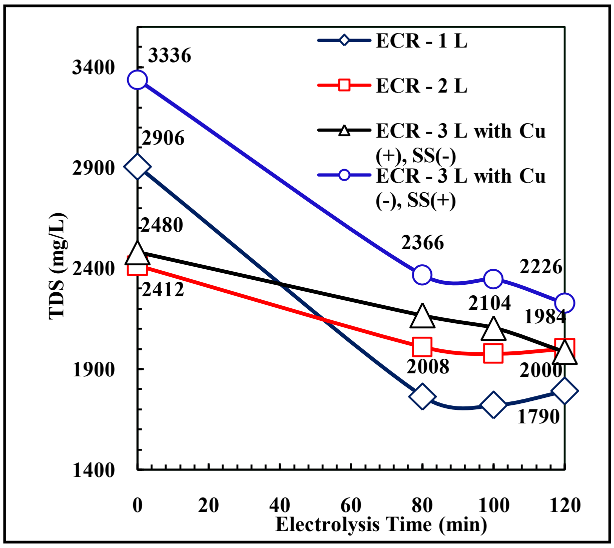


Fig. 4 Change in TDS values at different ET for KSWW without dilution for different SA/V

Operating conditions: ECR: 1L - agitation: 350 rpm; ECR: 2 & 3L - agitation: 250 rpm; 6E: SS & Cu; E-spacing: 1 cm; cell voltage: 30 V; current: 1.0 A; ET: 120 min & $TDS_0$: 2412 mg/L – 3336 mg/L.

For all SA/V, the general observation is the gradual decrease in TDS value at 120 min ET. An overall TDS removal efficiency of 38.40% was achieved at 120 min ET for 1 L ECR. The decrease in the TDS value synchronizes with the decrease in the COD removal values up to 80-100 min ET, after which a small increase occurs. Similarly for 2L ECR, the overall TDS removal efficiency obtained was only 17% with TDSf: 2000 mg/L at 120 min ET. For both the cases of 3L ECR, the plot showed that there was a gradual and continuous decrease in TDS values till 120 min ET irrespective of the polarity. However, the overall TDS removal efficiency obtained was 20% and 33% at 120 min ET for 3L ECR Cu (+) and SS (-) and 3L ECR Cu (-) and SS (+) respectively.

Fig. 5 shows the metal dissolution during BECC of KSWW without dilution for different SA/Vs.

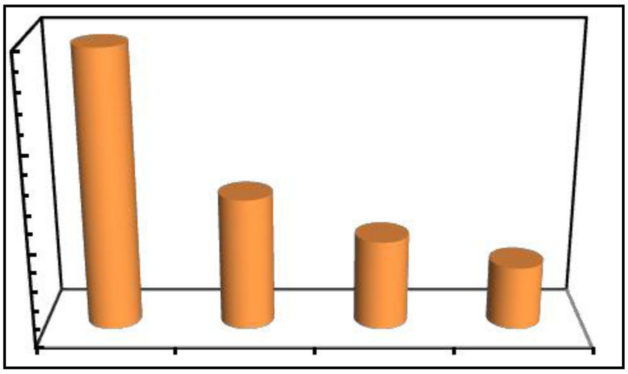

Fig. 5 : Metal dissolution pattern for KSWW without dilution for different SA/Vs

The overall electrode dissolution after batch ECC of KSWW was found to be 5857, 2788, 1895 and 1333 mg/L for 1, 2, and 3L ECRs and 3L ECR with Cu (-) and SS (+) respectively. It may be concluded that the electrode dissolution quantity decreases with corresponding increase in SA/V for the treatment of KSWW without dilution. It may be observed that the COD removal efficiency increased with increase in SA/V but with the decreased quantity

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of metal dissolution. The results of the experiments showed that dissolution of SS leads to the formation of $Fe^{2+}$ which is chemically oxidized into $Fe^{3+}$. The dissolution of SS is facilitated by pitting corrosion with chloride ions.

Treatment of KSWW without dilution using SS electrodes for SA/V: 50 m²/m³

Fig. 6 shows changes in TDS and COD values at different ET for KSWW without dilution using only six SS electrodes for SA/V: 50 $m^2/m^3$.

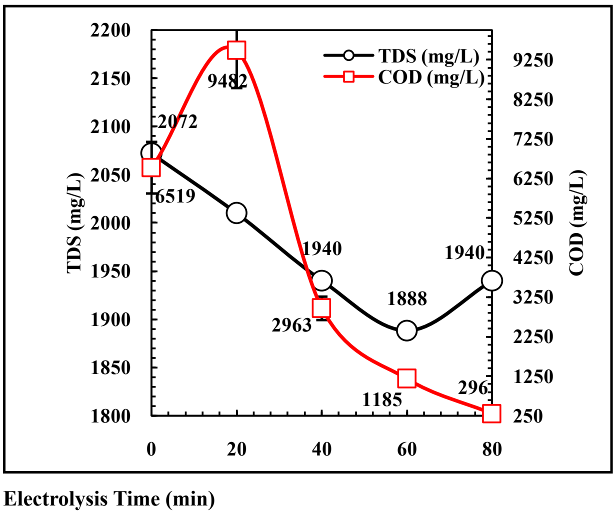


Fig. 6 : COD and TDS values at different ET for ECC of KSWW using SS electrodes for SA/V: 50 m²/m³

Operating conditions: ECR: 3L; agitation: 250 rpm; 6E: SS; E-spacing: 1 cm; Cell voltage: 30 V; Current: 0.9 A; ET: 80 min; $TDS_0$: 2072 mg/L & $COD_0$: 6519 mg/L.

On observing the results for ECC of KSWW using combination of SS and Cu, the 3L ECR which was found to be optimum and the same was adopted for treating KSWW without dilution using six SS electrodes to compare the COD and TDS removal efficiencies by combination of SS and Cu, SS electrodes alone.

From Fig. 6, it was observed gradual decrease in COD value from $COD_0$: 6519 mg/L to $COD_f$: 296 mg/L with 95.45% COD removal efficiency at 80 min ET, except an initial increase in COD value at 20 min ET; logical reason being a higher dissolution of electrodes at the beginning of the electrolysis process. There was a gradual decrease in TDS value from $TDS_0$: 2702 to 1888 mg/L at 60 min ET, after which slightly increased to 1940 mg/L with TDS removal efficiency of 6.37% at 80 min ET.

Metal dissolution of 1413.5 mg/L was observed for SS electrodes after ECC of raw KSWW without dilution, which is almost nearer to the metal dissolution observed in the case of 3L ECR with Cu and SS, 1333 mg/L and nominally very less compared to all the cases of ECC of raw KSWW.

The operating costs and energy consumption costs were calculated by considering electrical energy cost and electrodes cost [5].

### 1. Estimation of operating cost (OC)

The formula used to estimate the operating cost is:

$$\text{Operating Cost} = a \times C_{energy} + b \times C_{electrode}$$

where, a: Electrical energy price in Rs/kWh, b: Electrode material price in Rs/kg of electrode.

$C_{energy}$ = Cost due to Electrical energy (kWh/m³)
$C_{energy}$ is estimated by the formula:

$$C_{energy} = \frac{U \times I \times t}{v}$$

$C_{electrode}$ =Cost for electrode (kg of electrode/m³)
$C_{electrode}$ is given by the formula:

$$C_{electrode} = \frac{I \times t \times MW}{Z \times F \times v}$$

where, U: voltage (V), I: current (A), t: electrolysis time (s), V: volume of the reactor (m³), MW: molecular mass of metal ions, Z: no of electrons transferred and F: Faraday's constant (96487 C/mol).

### 4.3.2 Estimation of specific energy consumption

The formulae used to estimate the total energy consumption (TEC) and specific energy consumption (SEC) for ECC treatment are as follows:

$$TEC, \frac{kWh}{m^3}, E = \frac{(n-1) \times U \times I}{1000 \times Q}$$

$$SEC, \frac{kWh}{m^3}, SEC = \frac{U \times I \times t}{1000 \times v}$$

where, U: voltage (V), I: current (A), n: no of electrodes, t: electrolysis time (s), V: volume of the reactor (m³) and Q: wastewater rate (m³/h).

Optimal operating costs were found to be 0.25 and 0.40 US$/m³. Total and specific energy consumption at various optimal operating conditions for BECC of KSWW using combination of Cu and SS electrodes were estimated to be 82.5, 44 kWh/m³ respectively. Total and specific energy consumption costs at various optimal operating conditions for BECC of KSWW using SS electrodes were estimated to be 50 and 40 kWh/m³ respectively.

Table 2 shows the estimated energy consumption costs and operating costs for BECC of raw KSWW without dilution for different electrodes.

**Table 2 Estimation of energy consumption and operating cost**

| Grey water source | Operating parameters | TEC kWh/m³ | SEC kWh/m³ | Operating cost | |
|---|---|---|---|---|---|
| | | | | INR/ $m^3$ | US $/ $m^3$ |
| KSWW Cu & SS | 30V, 1.1 A, 6E | 82.5 | 44 | 15.08 | 0.25 |
| KSWW SS | 30V, 1.0 A, 6E | 50 | 40 | 24.11 | 0.40 |

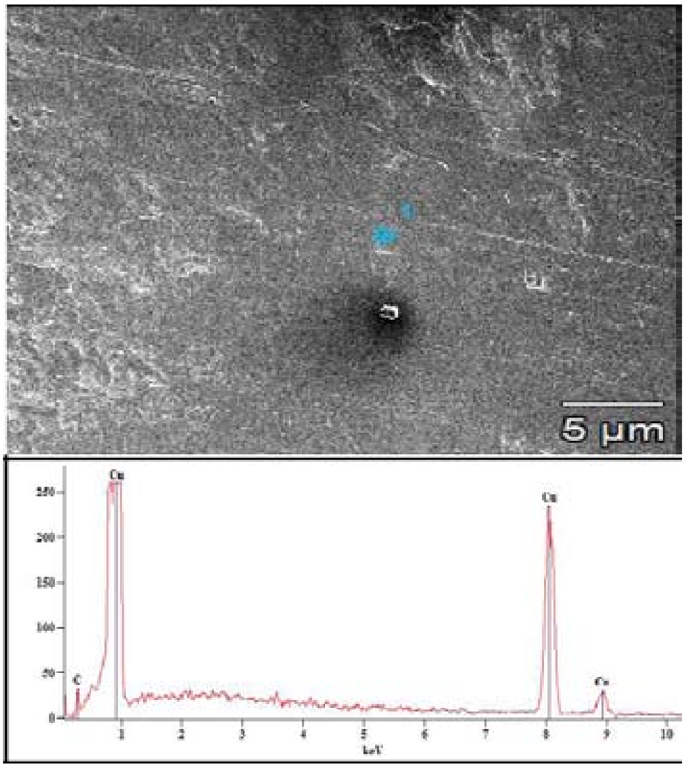


Image specifications: Resolution: 512 by 512, Pixel Size: 0.07 µm, Acc.Voltage: 15.0 kV, Magnification: 120

Fig. 7 EDS of Unused copper electrode of thickness 0.9 mm

Fig. 7 shows the various constituents of unused copper electrode of thickness 0.9 mm.
Unused Cu electrode showed the 87.74% of predominant copper and 12.26% of carbon respectively.

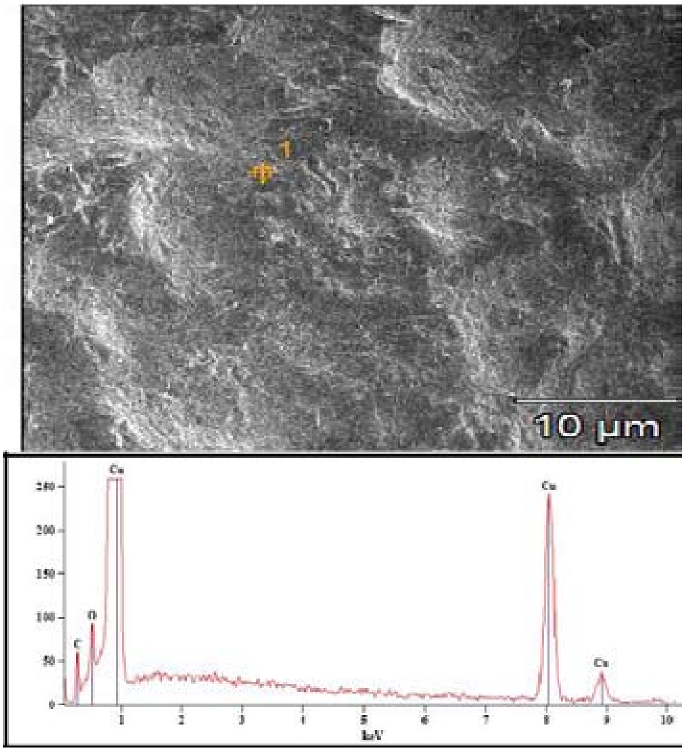


Image specifications: Resolution: 512 by 512, Pixel Size: 0.08 µm, Acc.Voltage: 15.0 kV, Magnification: 98

Fig. 8 EDS of used copper electrode of thickness 0.9 mm

Fig. 8 shows the various constituents of used copper electrode of thickness 0.9 mm adopted in BECC of KSWW. Used Cu electrode showed the 75.01% of copper, 18.82% of carbon and 12.26% of oxygen respectively.

## V. Conclusions

Raw KSWW showed very good response to 3L ECR of SA/V: 50 $m^2/m^3$ using six SS electrodes. For raw KSWW without dilution, COD and TDS removal efficiencies were comparatively less for 3L ECR with Cu and SS electrodes combinations.
Optimum COD and TDS removal efficiencies of 80% and 20% were achieved for BECC of KSWW using combination of SS and Cu electrodes under optimized operating conditions. It may be concluded that the COD removal efficiencies for different SA/V, the 3L ECR with Cu (+) and SS (-) may be considered as optimum operating condition for the treatment of KSWW without dilution using ECC. Of the two Cu-SS combinations in a 3L ECR, Cu anode and SS cathode bipolar arrangement showed increased COD removal of 80%.
The overall COD and TDS removal efficiencies of 95.45% and 6.37% were observed for BECC of KSWW using SS electrodes under optimized operating conditions. It may be inferred that SS electrodes resulted in improved COD removal efficiency when compared with the COD removal efficiency by combination of SS and Cu but with very marginal TDS removal efficiency.
By observing the COD removal efficiency, metal dissolution values, it is clear that, SS electrodes are found to be efficient for the removal of COD at an applied voltage of 30 V to treat raw KSWW without dilution though TDS removal was marginal. Applied cell voltage, Current, ET affect the dissolution of electrodes and hence also the removal of pollutants/ contaminants.
Optimal operating costs were found to be 0.25 and 0.40 US$/$m^3$. Specific energy consumption at various optimal operating conditions for BECC of KSWW using combination of SS and Cu electrodes and only six SS electrodes were estimated to be 44 and 40 kWh/$m^3$ respectively.
In addition to economic studies, technological studies are also required to prevent passivation of electrodes and to further optimise treatment parameters. Since, Cu electrode is highly reactive and corrodes easily and hence ED of Cu was more when compared to the SS electrodes.

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