Characterization of hazardous waste landfill leachate and its treatment through electrocoagulation

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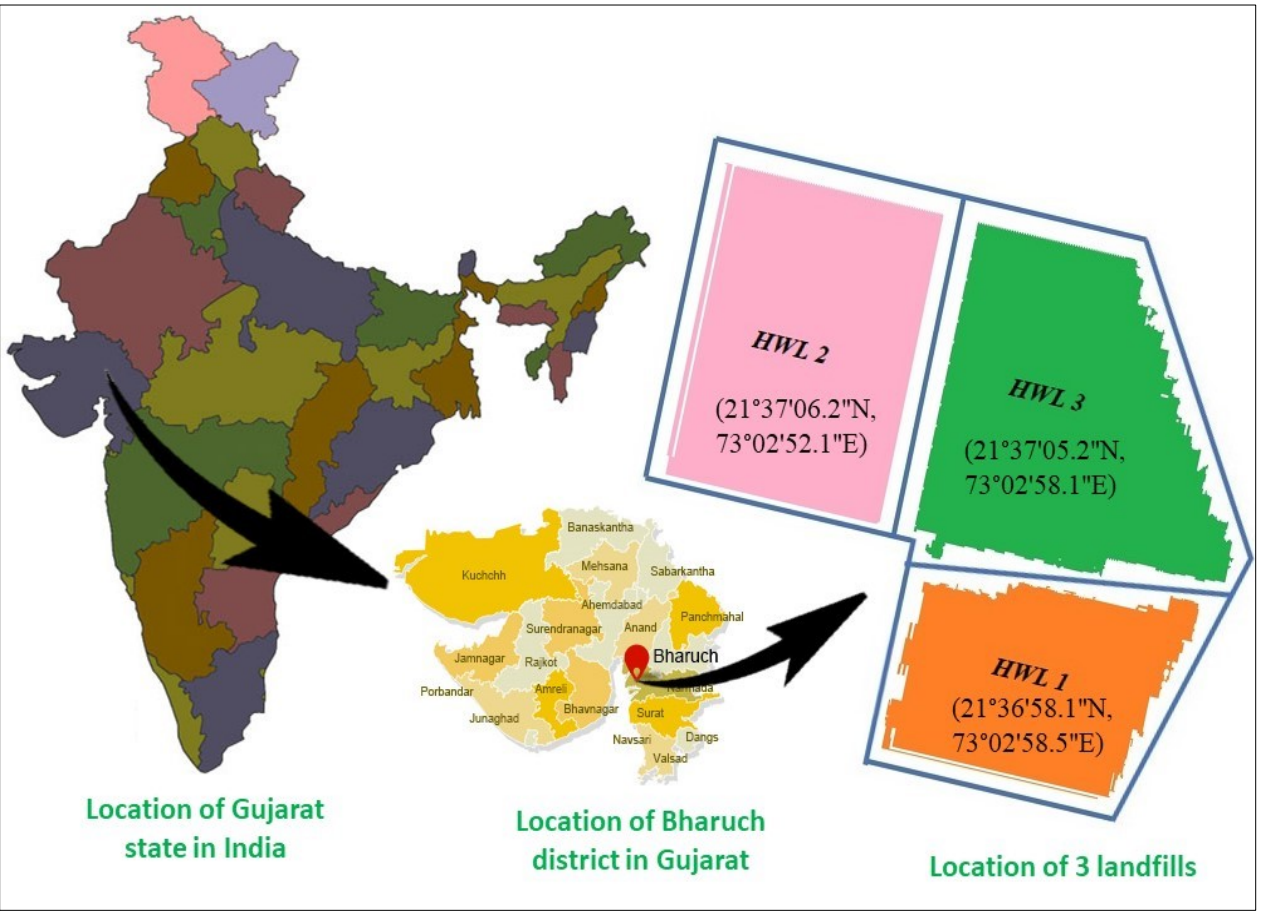
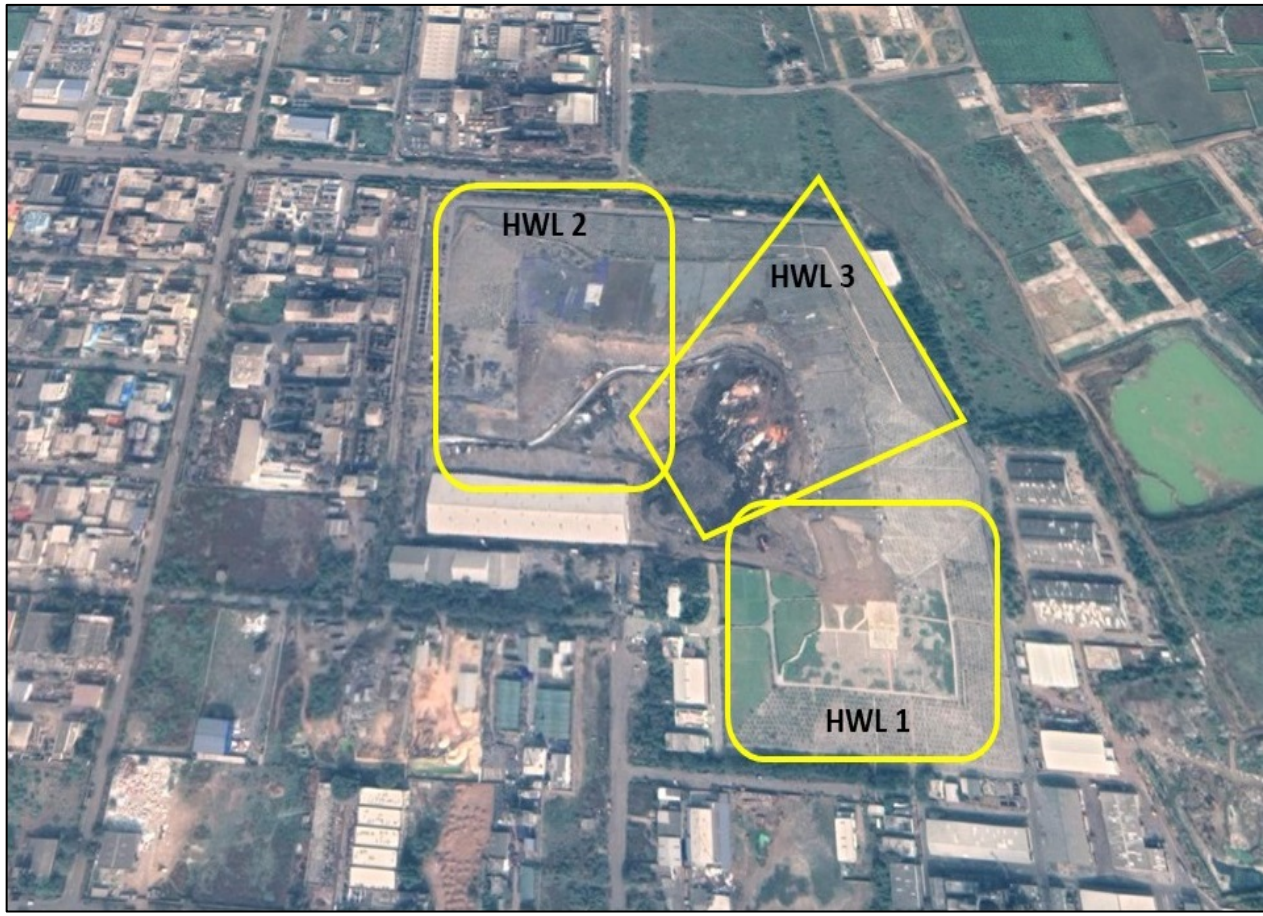
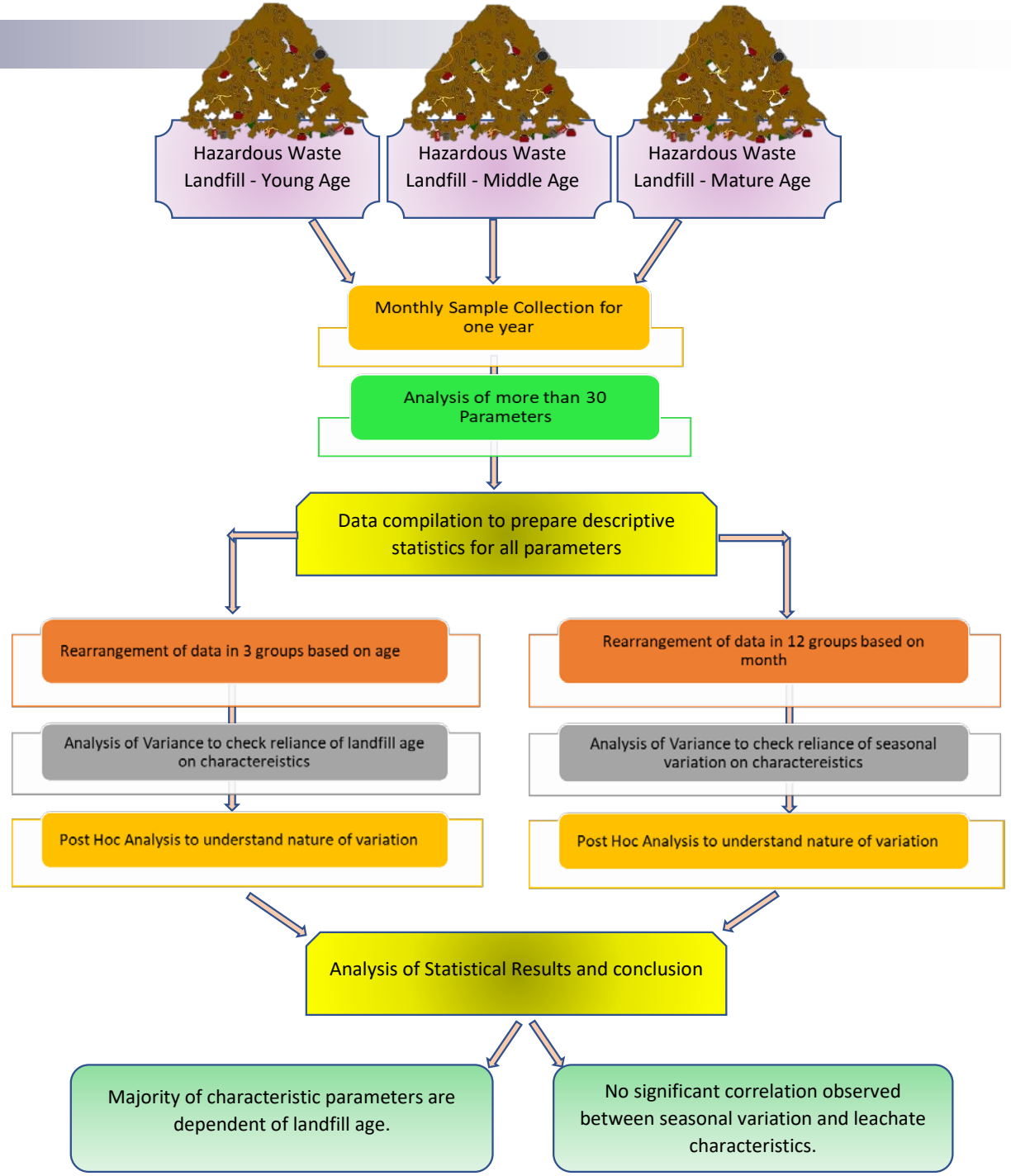
Study Area


HWL 2
(21°37'06.2"N,
73°02'52.1"E)
HWL 3
(21°37'05.2"N,
73°02'58.1"E)
HWL 1
(21°36'58.1"N,
73°02'58.5"E)
Banaskantha
Kuchchh
Mehsana
Sabarkantha
Ahemdabad
Panchmahal
Surendranagar
Anand
Jamnagar
Rajkot
Bharuch
Porbandar
Amreli
Junaghad
Bhavnagar
Surat
Navsari
Dangs
Valsad
Location of Gujarat state in India
Location of Bharuch district in Gujarat
Location of 3 landfills


HWL 2
HWL 3
HWL 1

Process Followed



Landfill Details

Reference Code	Area Occupied	Capacity	Age (yrs)	Year of inception
HW-I	36000 m^2	0.6 million tons	21	1997
HW-II	93000 m^2	1.7 million tons	11	2007
HW-III	12000 m^2	1.45 million tons	02	2016

WASTE TYPE

Industrial sludges, ETP sludges, Contaminated Barrels, Contaminated/Discarded Products

Parameters Studied

(32 Parameters)

Parameters	Methods
pH	IS:3025(P-11)83Re.02
Colour	IS:3025 (Part 4)
Oil and grease	APHA (22nd Ed)5220- / IS 3025 (Part 39)
Chemical oxygen demand (COD)	APHA (22nd Ed)5200-B
Biological oxygen demand (BOD)	APHA (22nd Ed)5210-B / IS 3025 (Part 44) 1993
Total Nitrogen (TN)	APHA (22nd Ed) 4500-N-B
Total Kjeldahl Nitrogen (TKN)	APHA (22nd Ed)4500-C / IS 3025 (Part 34)
Ammoniacal Nitrogen (AMM NIT)	APHA (22nd Ed)4500-C / IS 3025 (Part 34)
Total Phosphorus (TP)	APHA-4500-P. C
Total Hardness (TH)	EDTA Titration Method
Total Alkalinity (TA)	TITRATION METHOD
Total Dissolved Solid (TDS)	IS:3025 (Part 17)/ APHA (22nd Ed)2540 C
Total Suspended Solid (TSS)	IS:3025 (Part 17)/ APHA (22nd Ed)2540 D
Chloride (Cl)	IS:3025 (Part 24)
Sulfide	APHA (22nd Ed)4500-S2 F
Sulfate (SO_4^{2-})	APHA 4500-SO4 E
Total Phenol (TPh)	IS:3025(P-43)92. Re. 03

Parameters	Methods
Arsenic (As)	APHA 3111-AS-B
Boron (B)	APHA (22nd Ed) 4500-B C.
Barium (Ba)	AAS- APHA (22nd Ed) 3113-B
Calcium (Ca)	EDTA Titration Method
Cadmium (Cd)	APHA-3111- B
Chromium (Cr)	AAS- APHA (22nd Ed) 3111-B
Copper (Cu)	APHA 3111-CU-B
Iron (Fe)	IS:3025(Part-53)-2003
Mercury (Hg)	APHA-3111-HG-B
Potassium (K)	IS:3025 (Part 45)
Magnesium (Mg)	EDTA Titration Method
Sodium (Na)	IS:3025 (Part 45)
Zinc (Zn)	AAS- APHA (22nd Ed) 3113-B
Lead (Pb)	AAS- APHA (22nd Ed) 3113-B
Nickel (Ni)	AAS- APHA (22nd Ed) 3113-B

Descriptive statistics of leachate characteristics (general)

Sample Data Sets

Parameter		N	Mean	SD	Min	Max
AMM NIT (mg/l)	HWL1	12	1632	61	1544	1732
	HWL2	12	2394	85	2254	2526
	HWL3	12	2217	247	1854	2617
	Total	36	2081	363	1544	2617
BOD (mg/l)	HWL1	12	4886	255	4385	5339
	HWL2	12	13217	410	12491	13837
	HWL3	12	11747	930	9750	13380
	Total	36	9950	3729	4385	13837
COD (mg/l)	HWL1	12	15408	817	13167	16280
	HWL2	12	39689	1664	34644	40861
	HWL3	12	35098	2300	32093	38751
	Total	36	30065	10809	13167	40861
CHLORIDE (mg/l)	HWL1	12	63079	7518	50224	76496
	HWL2	12	133721	14164	109024	165969
	HWL3	12	130294	26828	65796	173527
	Total	36	109032	37350	50224	173527

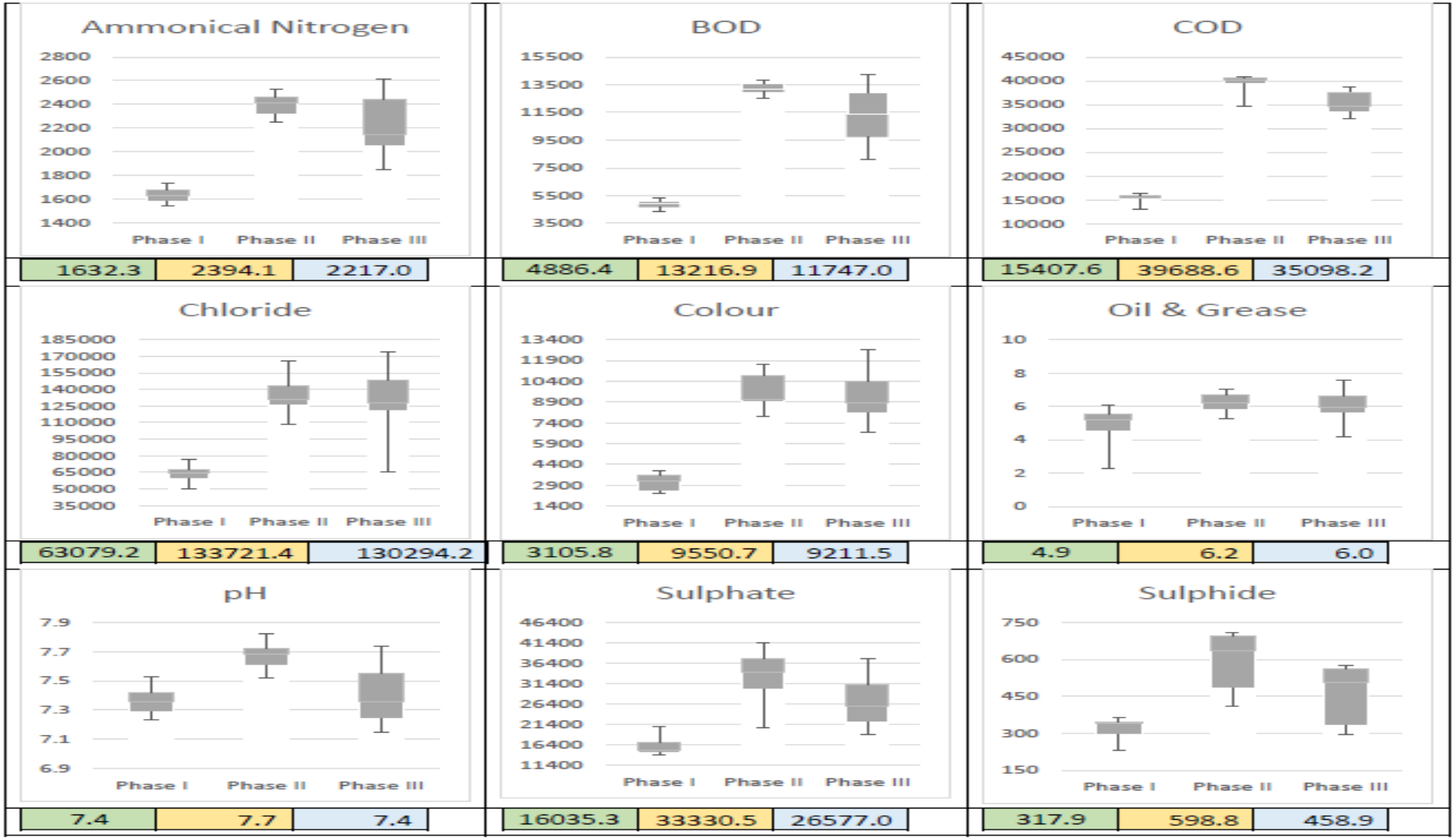
Descriptive statistics of leachate characteristics (metals)

Sample Data Sets

Parameter		N	Mean	Std. Deviation	Minimum	Maximum
Lead	HWL 1	12	2.380	1.209	.707	5.622
	HWL 2	12	3.670	2.207	.295	8.599
	HWL 3	12	3.363	1.934	.941	7.601
	Total	36	3.138	1.865	.295	8.599
Cadmium	HWL 1	12	.318	.159	.059	.511
	HWL 2	12	.573	.394	.006	.924
	HWL 3	12	.411	.297	.003	.706
	Total	36	.434	.310	.003	.924
Chromium	HWL 1	12	.637	.321	.214	1.220
	HWL 2	12	.902	.541	.529	2.146
	HWL 3	12	.628	.426	.241	1.811
	Total	36	.722	.445	.214	2.146
Nickel	HWL 1	12	2.737	1.774	.163	6.625
	HWL 2	12	4.807	2.828	.132	9.087
	HWL 3	12	4.254	2.398	.053	6.857
	Total	36	3.933	2.469	.053	9.087

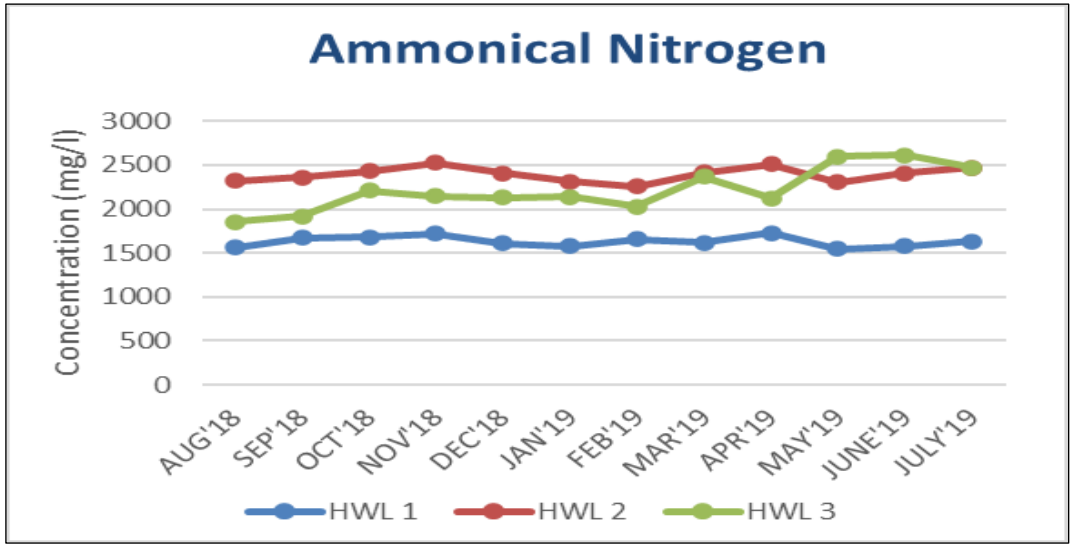
Mean values of the parameters of HWL leachate

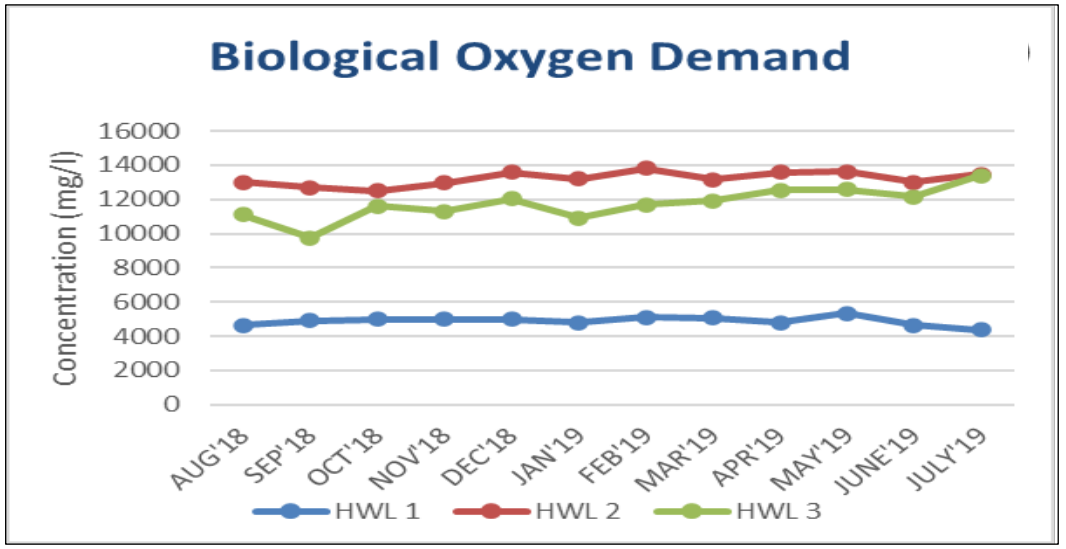
Sample Data Sets

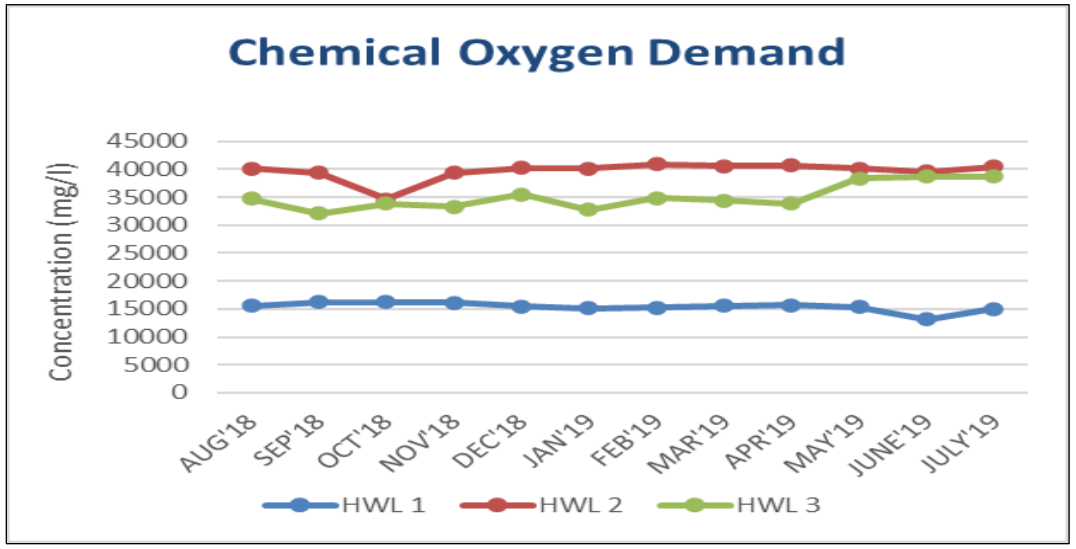


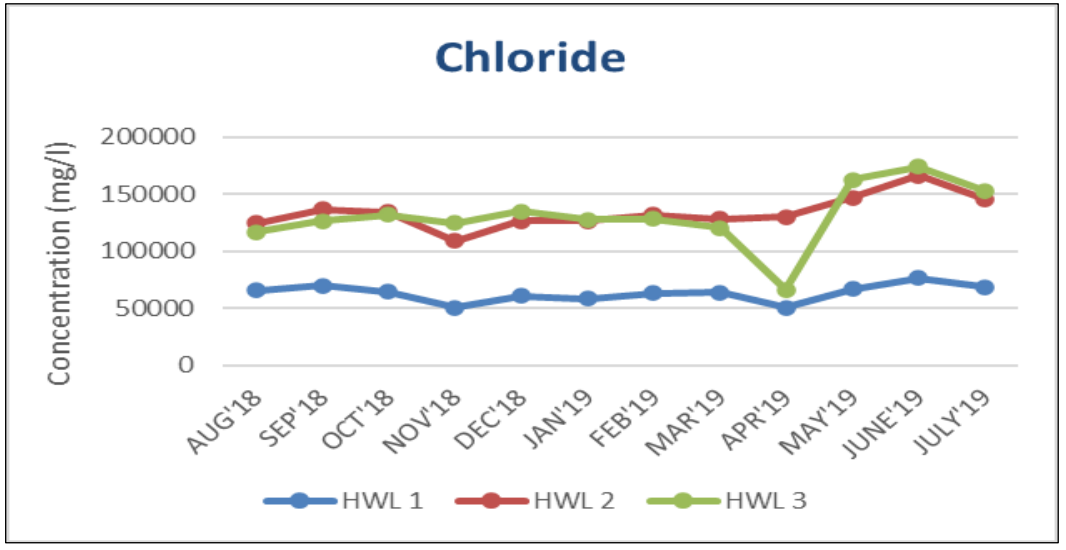
Monthly variation

Sample Data Sets









Leachate Pollution Index (LPI)

A tool to assess the leachate pollution potential from landfill sites particularly at places where there is a high risk of leachate migration and pollution of groundwater.

$$LPI = \frac{\sum_{i=1}^{m} wipi}{\sum_{i=1}^{m} wi}$$

where
LPI = Leachate pollution index,
wi = Weight of the ith pollutant variable
pi = Sub index score of the ith leachate pollutant variable
m = Number of leachate pollutant variables used in calculating LPI. (14 in our case)

Reference Code	Age (yrs)	LPI
HW-I	21	38.56
HW-II	11	45.36
HW-III	02	32.88

Effect of landfill age on leachate characteristics (ANOVA)

Sample Study

Analysis of Variance						
Parameter		Sum of Squares	Df	Mean Square	F	Sig.
AMMNIT	Between Groups	3813916	2	1906958	79	0.000
	Within Groups	792249	33	24008		
	Total	4606165	35			
SULFATE	Between Groups	1823000000	2	911700000	39	0.000
	Within Groups	773700000	33	23440000		
	Total	2597000000	35			
TH	Between Groups	57470000	2	28740000	7	0.003
	Within Groups	132100000	33	4001639		
	Total	189500000	35			
TOTPHOS	Between Groups	232	2	116	1	0.356
	Within Groups	3582	33	109		
	Total	3814	35			

Effect of landfill age (Post Hoc Analysis)

Sample Study

HWL	N	Ammoniacal Nitrogen			BOD			COD		
		1	2	3	1	2	3	1	2	3
HWL 1	12	1632.33			4886.383			1.540E4		
HWL 3	12		2217.000			1.174E4			3.509E4	
HWL 2	12			2394.10			1.321E4			3.969E4
Sig.		1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
HWL	**N**	**Sulphate**			**Sulphide**			**TDS**		
		1	2	3	1	2	3	1	2	3
HWL 1	12	1.603E4			317.908			1.518E5		
HWL 3	12		2.657E4			458.875			2.837E5	
HWL 2	12			3.333E4			598.847			3.080E5
Sig.		1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
HWL	**N**	**TKN**			**Chloride**			**Colour**		
		1	2	3	1		2	1		2
HWL 1	12	2379.661			6.307917E4			3105.801		
HWL 3	12		2740.000				1.302942E5			9211.541
HWL 2	12			3130.			1.337214E5			9550.724
Sig.		1.000	1.000	1.000	1.000		.898	1.000		.795

Effect of landfill age on HWL Leachate characteristics

LANDFILL AGE SIGNIFICANTLY AFFECTS THE LEACHATE'S CHARACTERISTICS
Up till middle age (10-15 years), mean concentration increases (although the rate of increment may be different) and during later age of landfill it start to decline (at different rate).
For some parameters like TN, mean concentration becomes steady in later stage.
For heavy metals two dominant trend exists : (i) Increases in metal concentration along with increase in landfill age (till middle age) and afterwards it subsides slowly. (ii)Another trend shows continuous decline in metal concentration with increase in landfill age.

Effect of Seasonal Variations (ANOVA)

Sample Study

Analysis of Variance (general parameters)						
		Sum of Squares	Df	Mean Square	F	Sig.
Ammoniacal Nitrogen	Between Groups	278552.203	11	25322.928	0.140	.99
	Within Groups	4327612.404	24	180317.183		
	Total	4606164.607	35			
Biological Oxygen Demand	Between Groups	5475576.375	11	497779.670	0.025	1.000
	Within Groups	481091014.935	24	20045458.956		
	Total	486566591.310	35			
Chemical Oxygen Demand	Between Groups	25263408.512	11	2296673.501	0.014	1.000
	Within Groups	4064146391.529	24	169339432.980		
	Total	4089409800.041	35			

Effect of Seasonal Variations(Post Hoc Analysis) Sample Study

	Total Phosphorus				Total hardness			Iron		
N	Month	1	2	3	Month	1	2	Month	1	2
3	Nov'18	20.916			July'19	5155.119		Oct'18	1.709	
3	July'19	27.811			Jan'19	6446.304	6446.304	Sept'18	4.307	4.307
3	Jan'19	28.151			Nov'18	7236.317	7236.317	July'19	5.049	5.049
3	Oct'18	28.793			Dec'18	7462.388	7462.388	May'19	5.062	5.062
3	Feb'19	29.857			March'19	8109.031	8109.031	March'19	5.378	5.378
3	April'19	31.459			Feb'19	8389.436	8389.436	April'19	5.559	5.559
3	June'19	31.806	31.806		Oct'18	8440.190	8440.190	Jan'19	5.643	5.643
3	March'19	32.479	32.479		April'19	8551.000	8551.000	Aug'18	5.677	5.677
3	May'19	33.186	33.186		June'19	8754.777	8754.777	June'19	5.882	5.882
3	Dec'18	34.357	34.357		May'19	8763.833	8763.833	Feb'19		6.082
3	Aug'18		48.898	48.898	Aug'18	10721.952	10721.952	Nov'18		6.570
3	Sept'18			55.750	Sept'18		11524.984	Dec'18		8.427
	Sig.	.239	.054	.945	Sig.	.069	.127	Sig.	.051	.056

	Cadmium				Chromium			
N	Month	1	2	3	Month	1	2	3
3	August'18	0.023			September'18	0.348		
3	October'18	0.037	0.037		December'18	0.435		
3	September'18	0.059	0.059	0.059	May'19	0.545		
3	November'18	0.193	0.193	0.193	February'19	0.551		
3	January'19	0.538	0.538	0.538	July'19	0.570		
3	March'19	0.589	0.589	0.589	January'19	0.578		
3	December'18	0.603	0.603	0.603	April'19	0.594		
3	June'19	0.617	0.617	0.617	March'19	0.596		
3	July'19	0.619	0.619	0.619	November'18	0.664	0.664	
3	May'19		0.632	0.632	June'19	0.667	0.667	
3	February'19			0.644	October'18		1.389	1.389
3	April'19			0.650	August'18			1.726
	Sig.		.052	.052	.055	Sig.	.903	.054

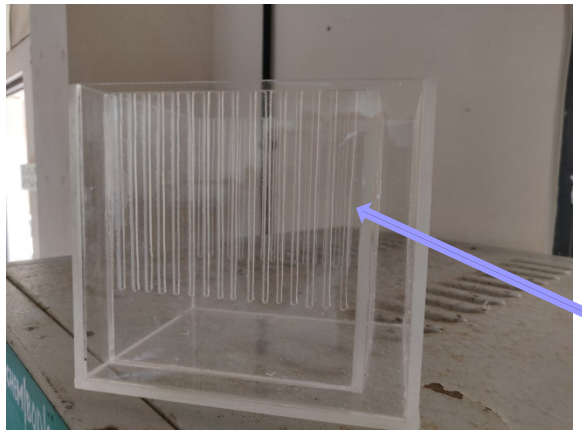
Effect of seasonal variations on HWL Leachate characteristics

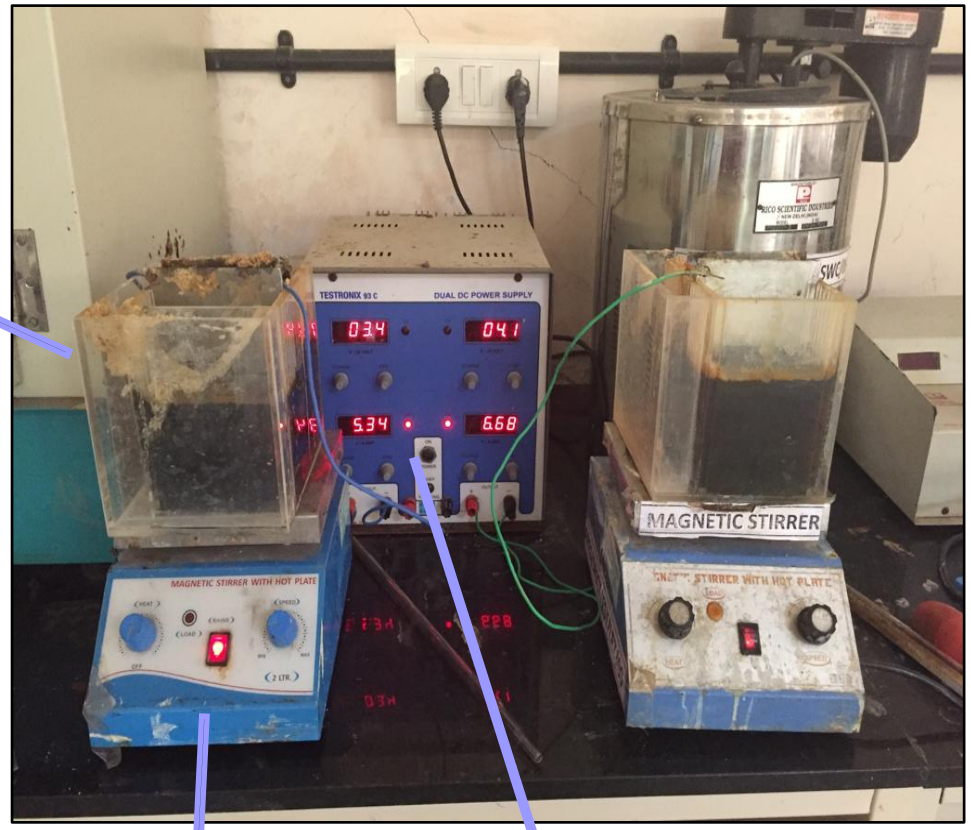
SEASONAL VARIATION SIGNIFICANTLY AFFECTS THE CONCENTRATION OF LEACHATE PARAMETERS BUT THE DEPENDENCY IS VERY RANDOM AND NO SPECIFIC PATTERN COULD BE SPOTTED

Metals exhibit variation in means during different months and for nickel and lead this variation is maximum

No trend in the parameters due to seasonal variation is because hazardous waste landfills are completely covered with HDPE liner, and all kind of interaction of waste from external environment are minimized

Experimental set up and Procedure





Magnetic Stirrer

Dual port Rectifier

REACTOR

MOC : Acrylic
Capacity : 1 ltr
Dimension : 12x10x14 cm
Slots : 16
Minimum distance between two slots : 8 mm

- Checking initial pH and COD of leachate sample
- Taking 1 liter leachate in reactor
- Connecting proper electrodes at proper distance with rectifier
- Initializing the process and taking samples at regular intervals of 30 min
- Analyzing parameters like COD, heavy metals etc from the final treated leachate
- Repeating the experiment with changing electrode and other operating parameters

Selection of Electrode

Sample of leachate = 1liter

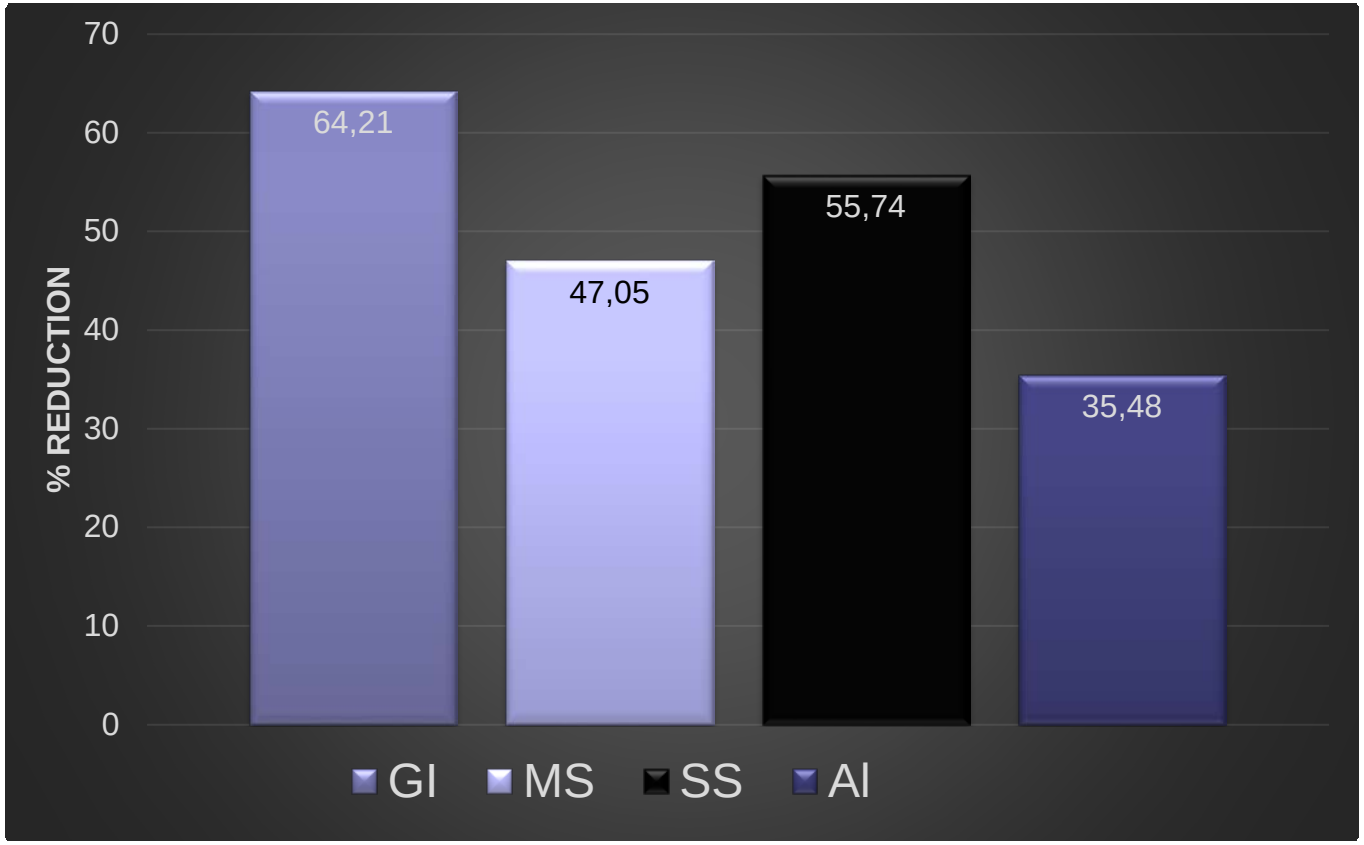
pH = 7.2

Electrolysis time – 180 min

Current density : 31.23 A/cm^2

Distance between electrodes = 1.5 cm

Type of electrode	Initial COD	% Reduction in COD
GI	34300	64.21
MS	34000	45.16
SS	31000	55.74
Al	31000	34.45



GI & SS can be preferred electrode giving high COD reduction

SELECTION OF ELECTRODE

ANOVA

CODRED

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1500.623	3	500.208	44.112	.000
Within Groups	90.716	8	11.340		
Total	1591.339	11			

Post Hoc Test

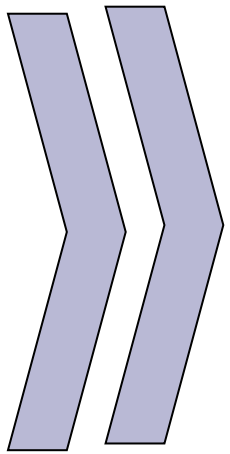
CODRED

Tukey HSD[a]

ELECTRODE	N	Subset for alpha = 0.05		
		1	2	3
AI	3	34.4500		
MS	3		45.1600	
SS	3			55.7533
GI	3			64.2100
Sig.		1.000	1.000	.060

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.



GI and SS as preferable electrode

Other options tried for enhancing COD reduction

- Multi Electrode
- GI-MS Combination
- GI-SS Combination
- Al-SS Combination
- Mix SS grades in combination
- EC with addition of H2O2
- EC with Microwave radiation
- Addition of Electrolyte

Conclusion

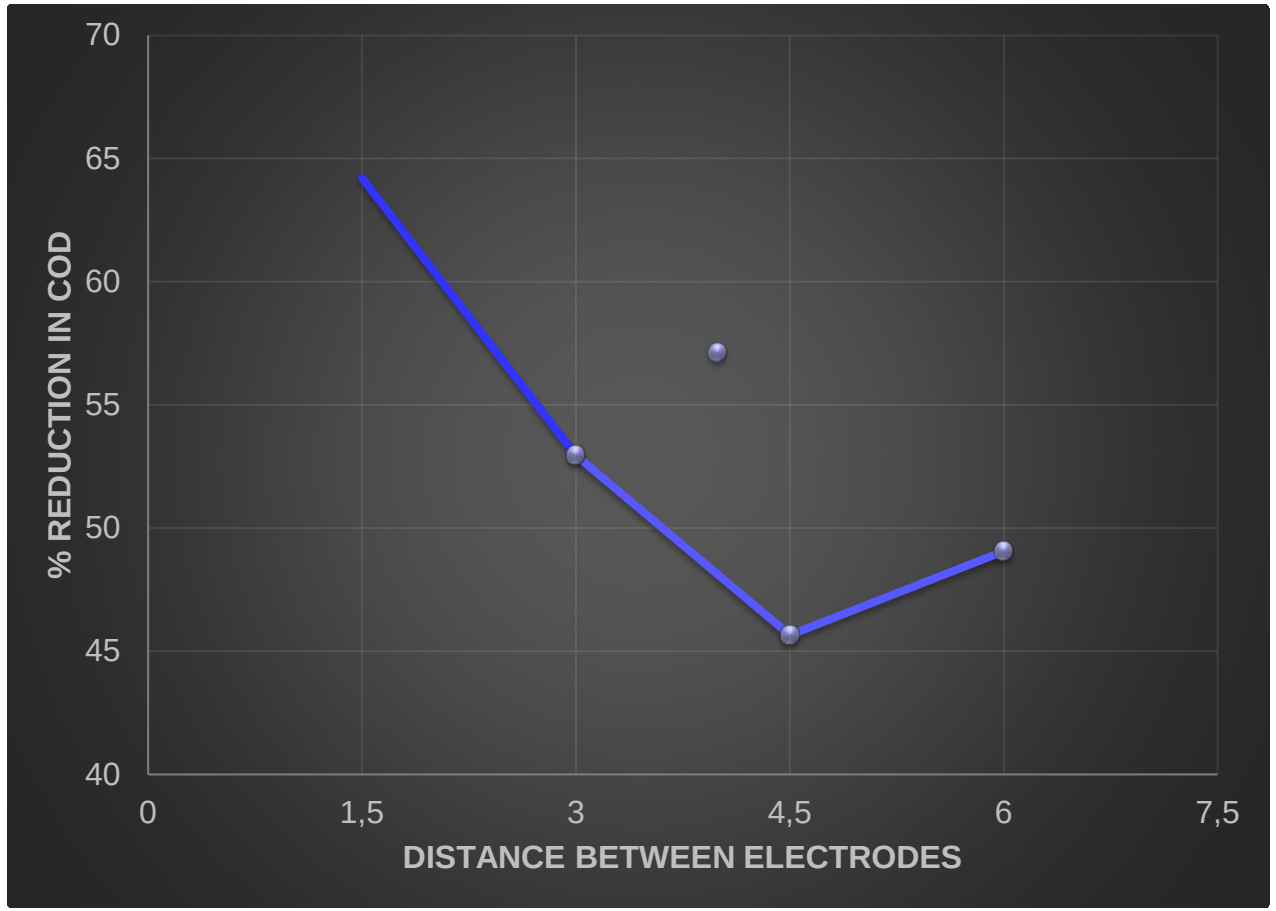
GI is the optimum electrode pertaining to the COD and colour reduction obtained in preliminary experiments

Experiments with GI plates (Varying distance)

Sample of leachate = 1liter	pH = 7.2
Electrolysis time – 240 min	Current density : 31.23 A/cm^2

No of electrodes : 02

Distance between electrodes	% reduction in COD
1.5 cm	64.21
3 cm	52.96
4.5 cm	45.66
6.0 cm	49.06



1.5 cm distance - Optimum for EC using GI electrodes

EFFECT OF DISTANCE

ANOVA

CODRED

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	585.253	3	195.084	9.950	.004
Within Groups	156.857	8	19.607		
Total	742.110	11			

Post Hoc Test

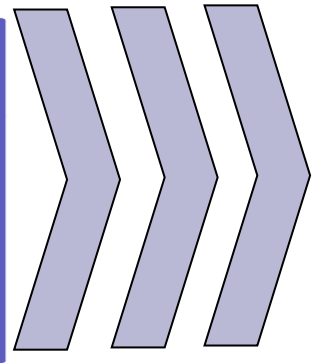
CODRED

Tukey HSD[a]

VAR.DIST	N	Subset for alpha = 0.05	
		1	2
4.5 cm	3	45.6567	
6 cm	3	49.0633	
3 cm	3	52.9767	52.9767
1.5 cm	3		64.2100
Sig.		.256	.057

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.



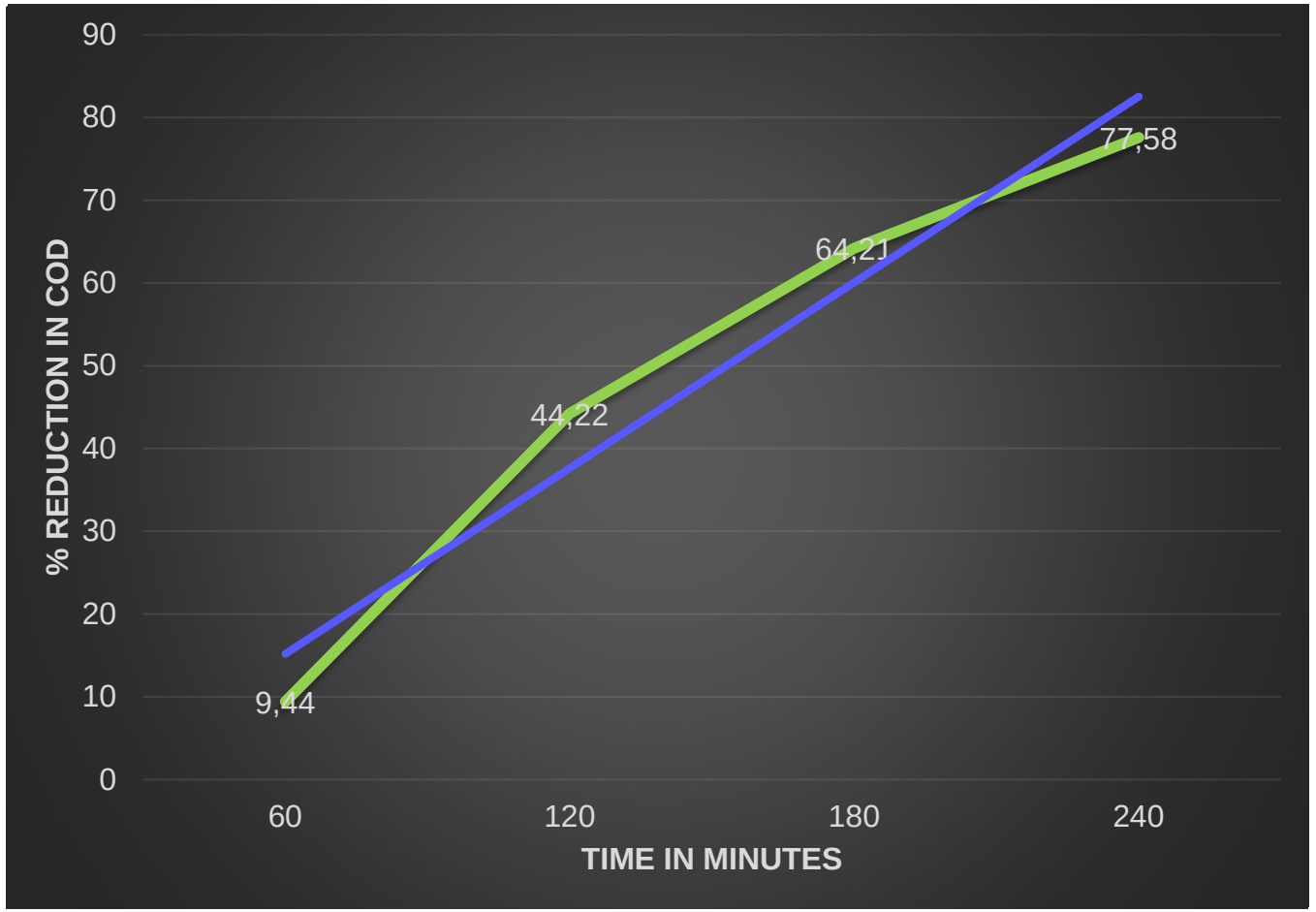
I.5 cm as preferable inter-electrode distance

Experiments with GI plates (Varying time)

Sample of leachate = 1liter	pH = 7.2
Distance = 1.5 cm	Current density : 31.23 A/cm^2

No of electrodes : 02

Electrolysis time (min)	% reduction in COD
60	9.44
120	44.22
180	64.21
240	77.58



Electrolysis time is directly proportional to % reduction in COD

EFFECT OF ELECTROLYSIS TIME

ANOVA

CODRED

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7936.987	3	2645.663	257.433	.000
Within Groups	82.217	8	10.277		
Total	8019.204	11			

Post Hoc Test

CODRED

Tukey HSD[a]

ET	N	Subset for alpha = 0.05			
		1	2	3	4
60 min	3	9.3167			
120 min	3		44.2200		
180 min	3			64.2100	
240 min	3				77.5800
Sig.		1.000	1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

ET is directly proportional to COD reduction

Experiments with GI plates (varying current density)

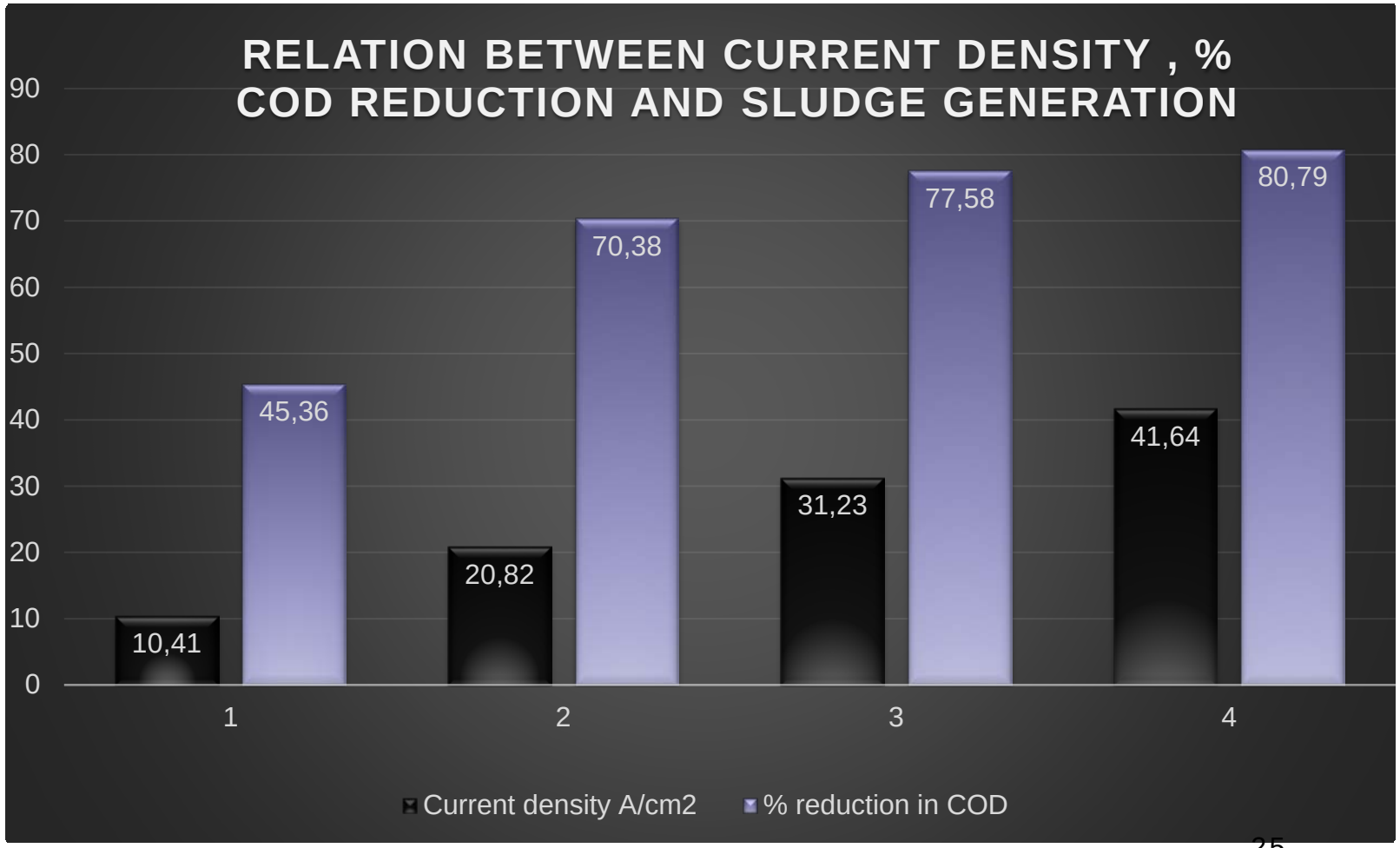
Sample of leachate = 1liter

pH = 7.2

Distance = 1.5 cm

Electrolysis time = 240 min

Current density A/cm²	% reduction in COD
10.41	45.36
20.82	70.38
31.23	77.58
41.64	80.79



EFFECT OF CURRENT DENSITY

ANOVA

CODRED

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2316.699	3	772.233	165.753	.000
Within Groups	37.271	8	4.659		
Total	2353.970	11			

Post Hoc Test

CODRED

Tukey B[a]

CD	N	Subset for alpha = 0.05		
		1	2	3
10.41	3	45.3633		
20.82	3		70.3767	
31.23	3			77.5800
41.64	3			80.7867

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

CD is directly proportional to COD reduction

Experiments with GI plates (effect of pH)

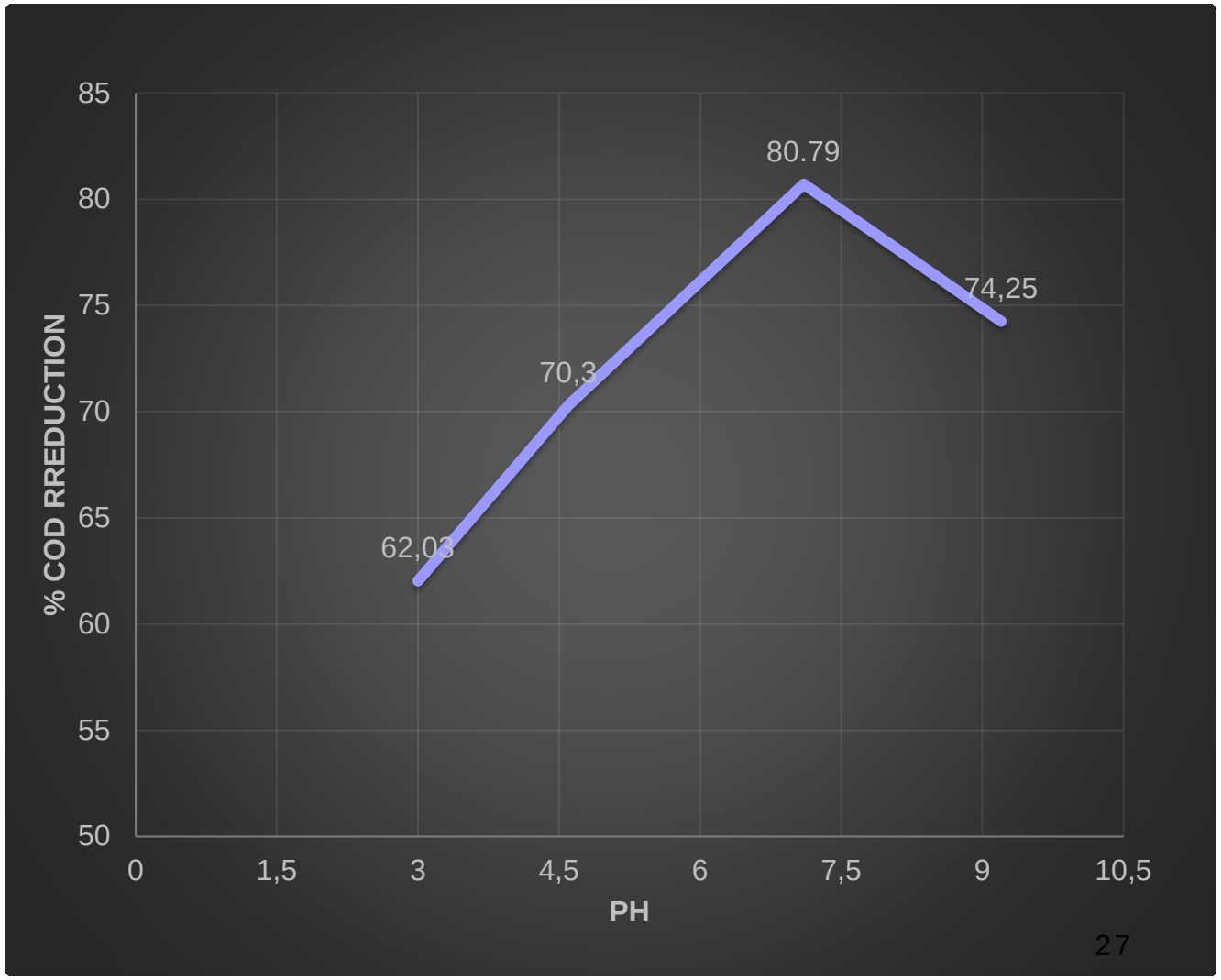
Sample of leachate = 1liter

Current density : 41.64 A/cm^2

Distance = 1.5 cm

Electrolysis time = 240 min

Initial pH	Final pH	% reduction
3	5.3	62.03
4.6	6.1	70.3
7.2	7.5	80.79
9.2	10.5	74.25



EFFECT OF pH

ANOVA

CODRED

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	553.373	3	184.458	47.928	.000
Within Groups	30.789	8	3.849		
Total	584.162	11			

Post Hoc Test

CODRED

Tukey HSD[a]

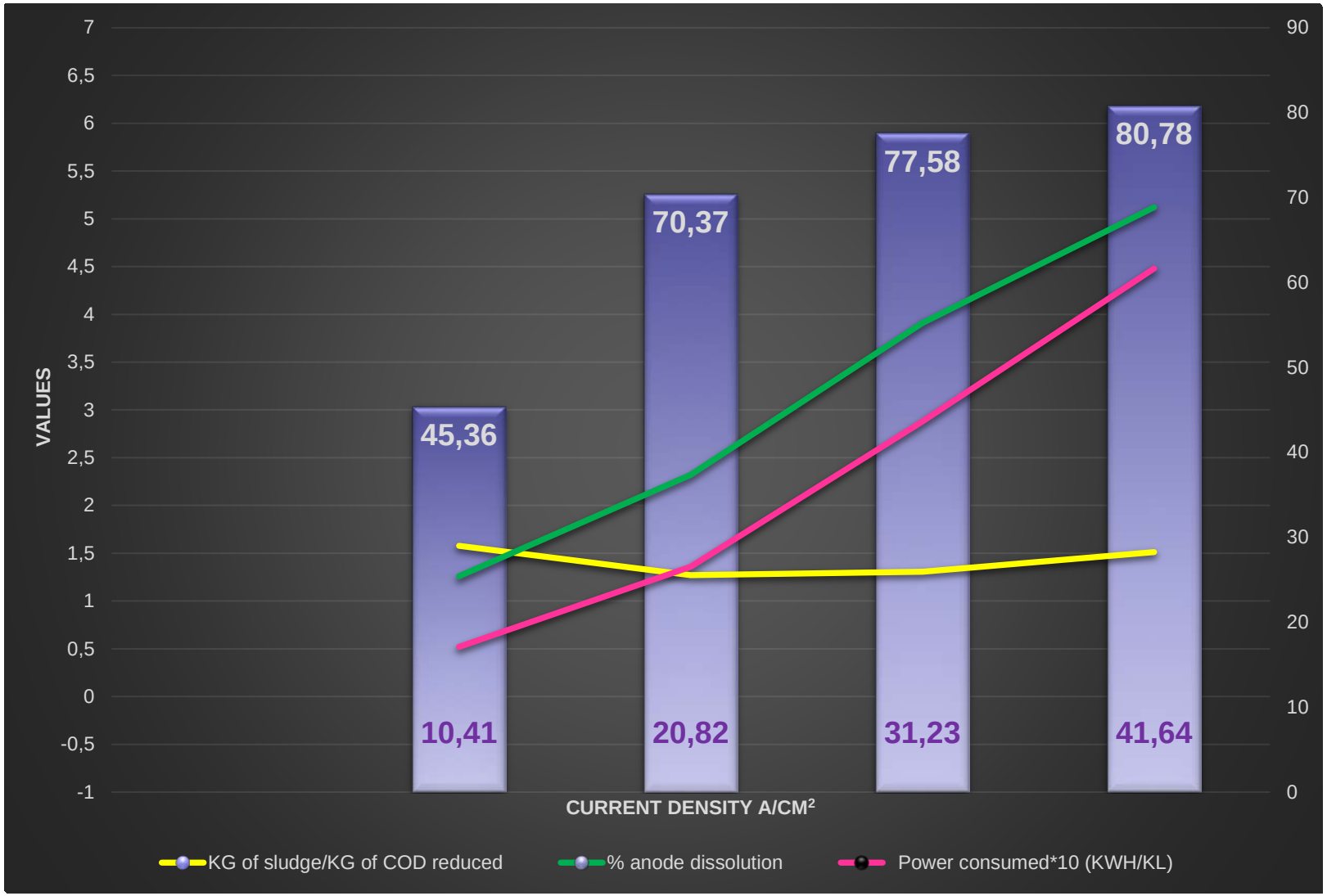
PH	N	Subset for alpha = 0.05		
		1	2	3
3	3	62.0333		
4.6	3		70.3000	
10	3		74.2633	
7.1	3			80.7867
Sig.		1.000	.139	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Neutral pH is preferable

SLUDGE, ANODE DISSOLUTION, POWER CONSUMPTION & COD REDUCTION



COD REDUCTION
80.79%

CURRENT DENSITY
41.64 A/cm²

% ANODE DISSOUTION:
5.12

POWER CONSUMED
44.8 KWH /KL

KG SLUDGE /KG COD REDUCED
1.513 KG

DOE for Optimization

Central Composite Design

Factors: 3 Replicates: 1
Base runs: 26 Total runs: 26
Base blocks: 1 Total blocks: 1

Two-level factorial: Full factorial

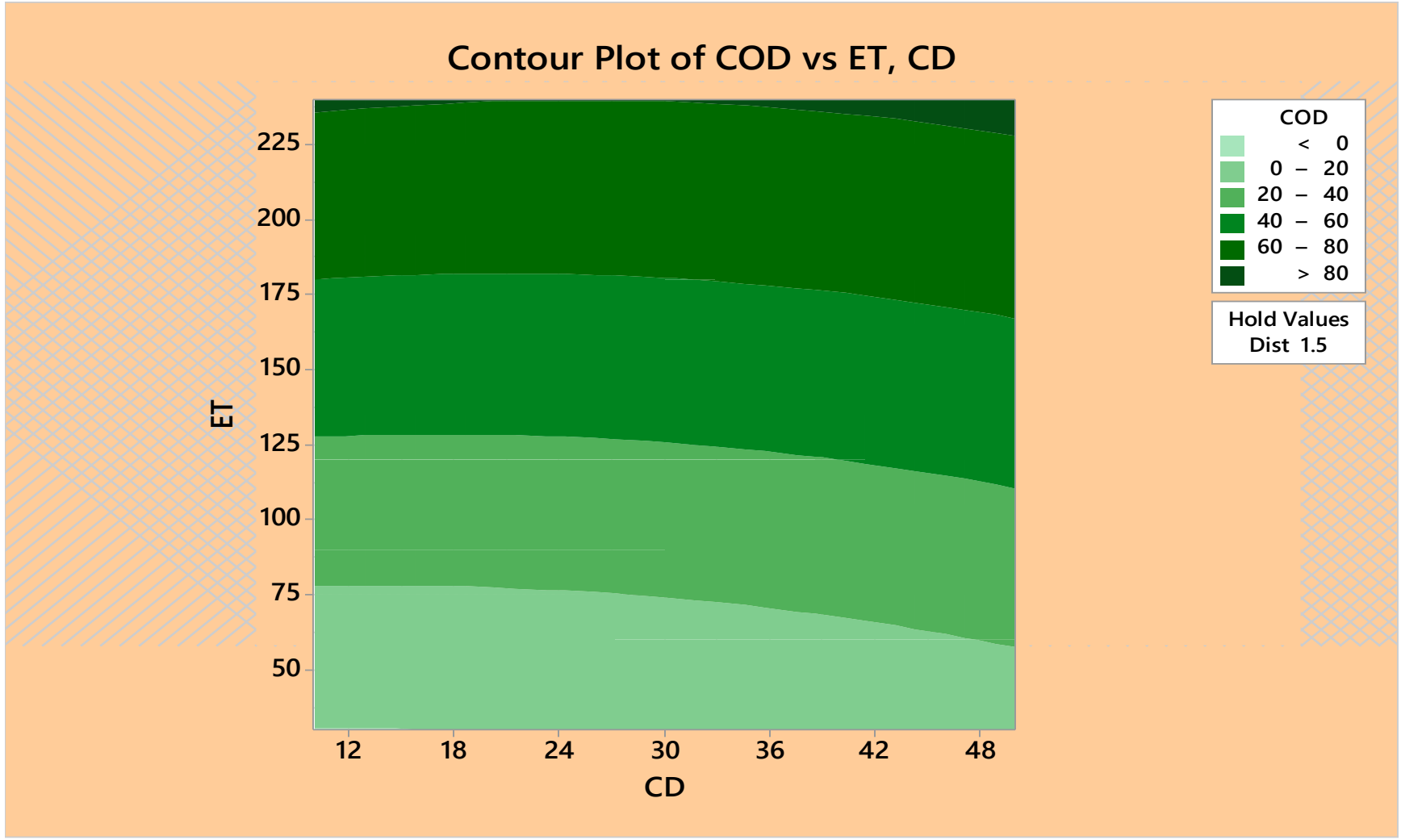
Cube points: 8
Center points in cube: 10
Axial points: 8
Center points in axial: 0

α: 1.41421

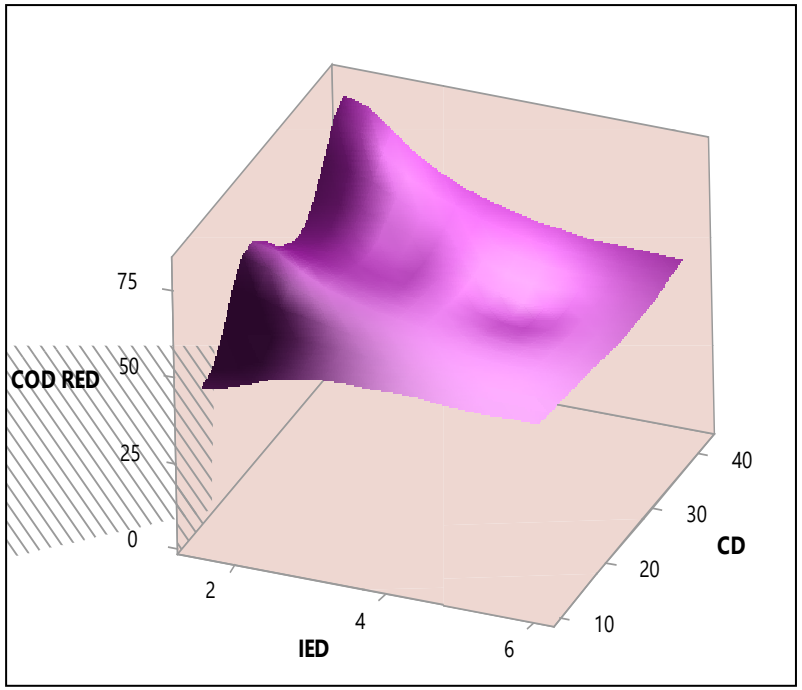
Personal comments: Factors>Axial Points
Design> Full with 13 runs

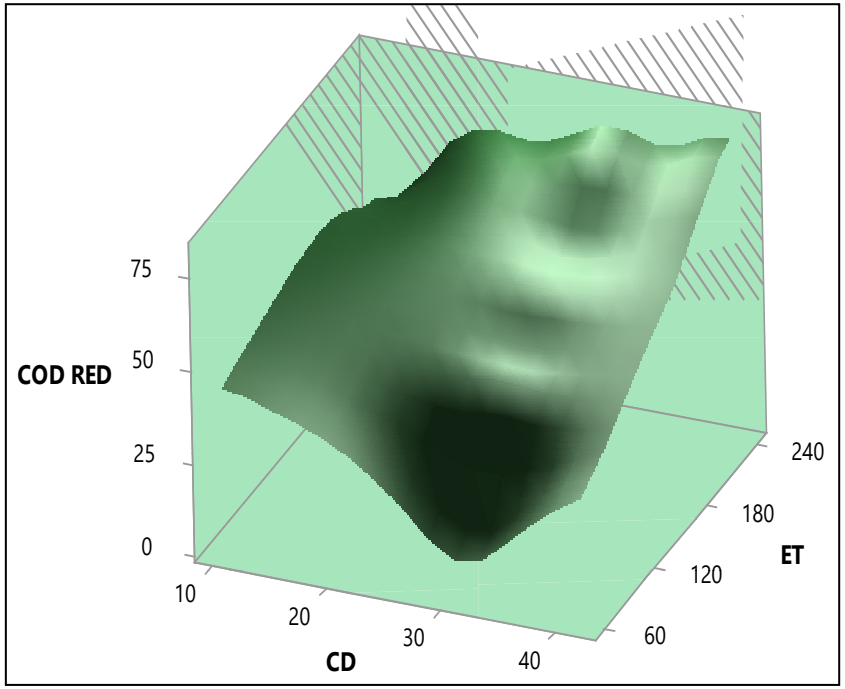
Std Order	RunOrder	PtType	Blocks	CD	ET	Dist	% COD Red
13	1	0	1	30	135	1.5	43.3
2	2	1	1	44.14214	60.75379	1.5	20.7
24	3	0	1	30	135	3	37.9
11	4	0	1	30	135	1.5	43.3
16	5	1	1	15.85786	209.2462	3	58.6
9	6	0	1	30	135	1.5	43.3
12	7	0	1	30	135	1.5	43.3
8	8	-1	1	30	240	1.5	76.7
1	9	1	1	15.85786	60.75379	1.5	10.3
23	10	0	1	30	135	3	37.9
19	11	-1	1	50	135	3	34.5
22	12	0	1	30	135	3	37.9
18	13	-1	1	10	135	3	41.4
5	14	-1	1	10	135	1.5	41.4
3	15	1	1	15.85786	209.2462	1.5	75.9
4	16	1	1	44.14214	209.2462	1.5	72.4
17	17	1	1	44.14214	209.2462	3	72.4
15	18	1	1	44.14214	60.75379	3	17.2
10	19	0	1	30	135	1.5	43.3
14	20	1	1	15.85786	60.75379	3	10.3
20	21	-1	1	30	30	3	1.2
26	22	0	1	30	135	3	37.9
25	23	0	1	30	135	3	37.9
21	24	-1	1	30	240	3	65.5
6	25	-1	1	50	135	1.5	48.3
7	26	-1	1	30	30	1.5	3.3

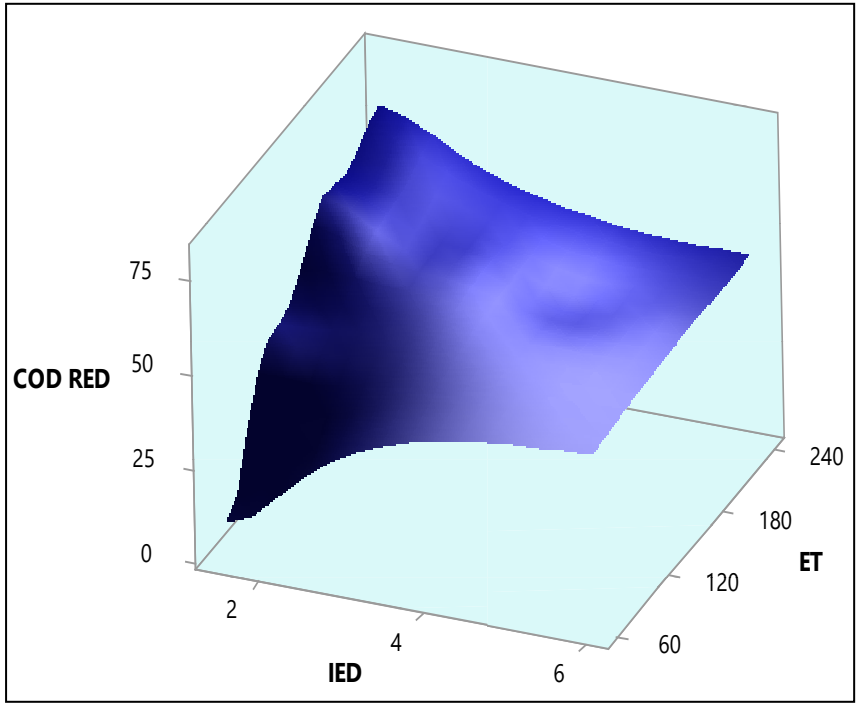
Response Surface Optimizer



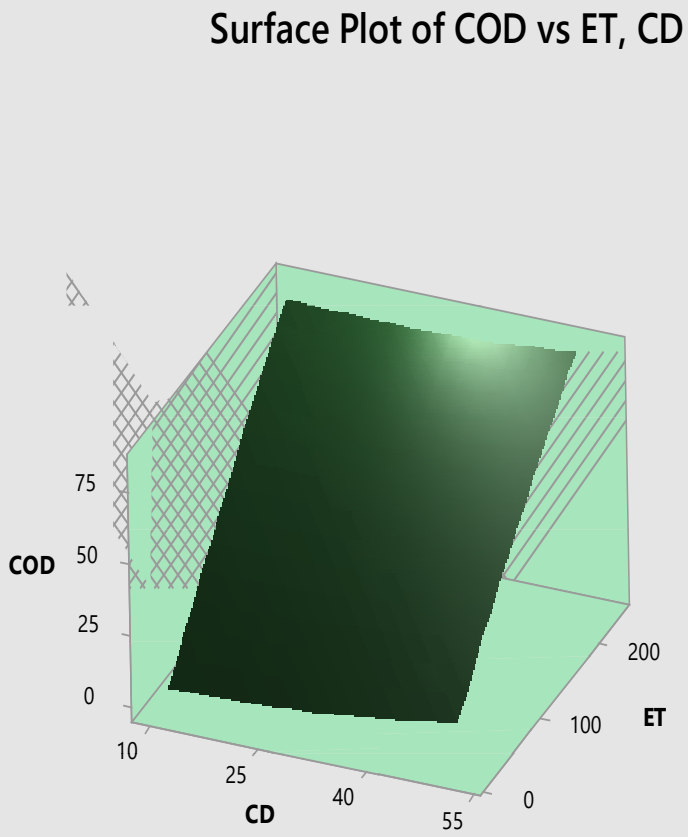
Surface plot diagrams







Response Surface Optimizer



Optimizer Result

Variable	Setting
CD	50
ET	240
Dist	1.5

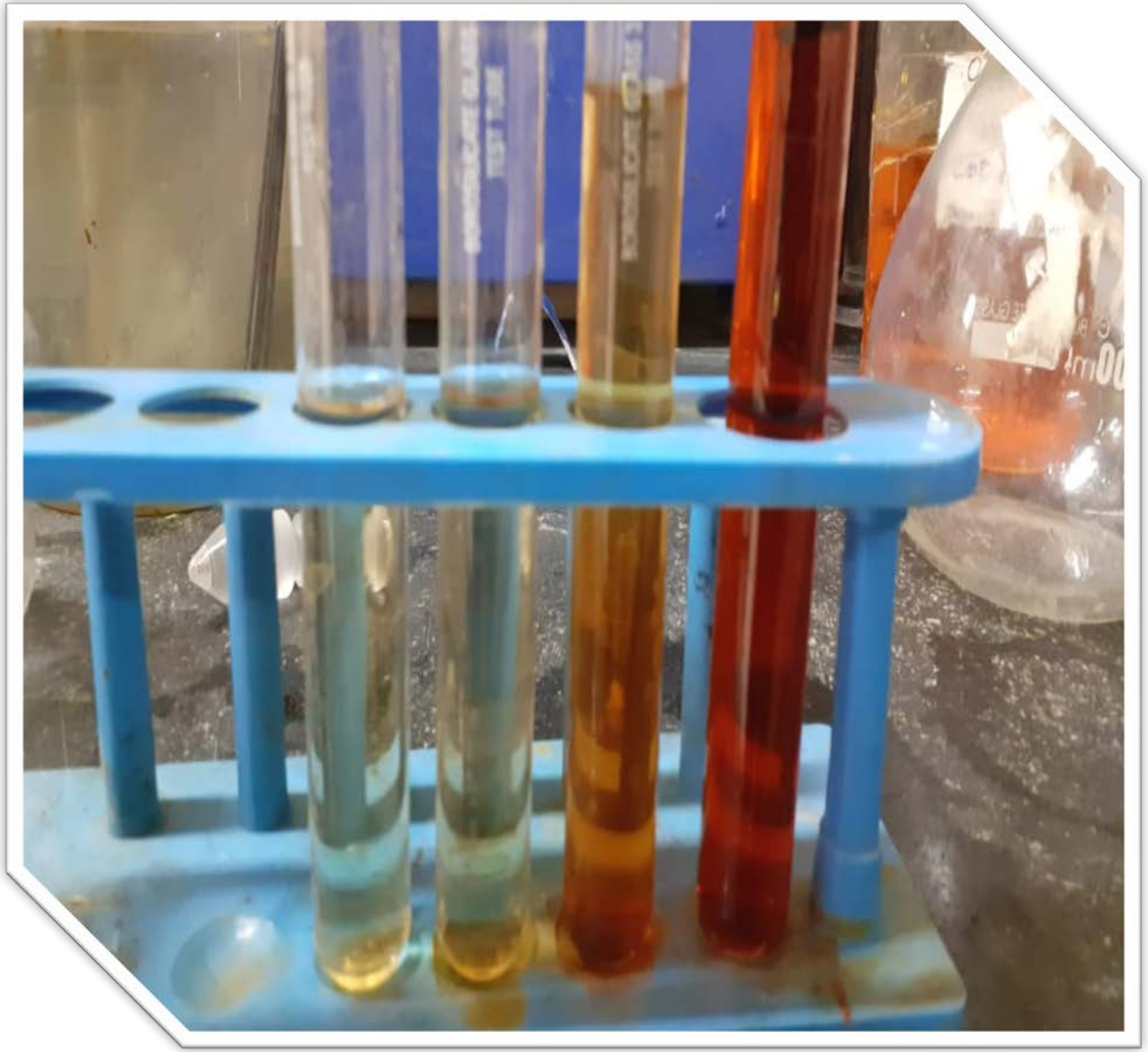
COD Reduction: 89.7%

FINAL CONCLUSIONS

OPTIMUM PARAMETERS FOR ELECTROCOAGULATION

- ELECTRODE MATERIAL: GALVANISED IRON (GI)
- DISTANCE BETWEEN ELECTRODES: 1.5 CM
- ELECTROLYSIS TIME: 240 MINUTES
- CURRENT DENSITY: 50 A/cm^2
- pH: 7.2

% REDUCTION IN PARAMETERS FOR TREATED LEACHATE



CADMIUM: 58 .1%

COD: 89.7 %

TOC: 54.7%

COLOUR: 84.0 %

ZINC: 63.6%

LEAD: 52.5%

PHENOLIC COMPOUNDS : 42.4 %

THANKS