Optimization of Cement Kiln Dust Usage for Removing Different Metals from Synthetic Raw Water

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Abstract: A pilot plant was constructed at El-Amerea water treatment plant to investigate the effect of using cement kiln dust CKD as a filter media. Different flow techniques were applied to optimize the removal efficiency of manganese and iron from Synthetic raw water. Different rates of filtration were applied 100, 200, 250 and 300 m^3/m^2.day. It was observed that, rate of filtration 200m^3/m^2.d can be used and is found to be more suitable for the cement kiln dust particles properties. Different CKD depths were used 20, 40 and 60 cm respectively, fixed bed and rate of filtration 200m^3/m^2.day. It was noticed that, 40 cm CKD depth is sufficient for removing iron and manganese from raw water. Different flow techniques were applied fixed and fluidized bed. Fluidized bed is better more than fixed bed technique. The removal efficiencies for iron and manganese reached to 100% in different cases. CKD was used as a primary coagulant with different doses ranged from 20mg/l to 120 mg/l. It was observed that, CKD was effective for iron but for removing manganese was not efficient. It was noticed that, when the pH value is raised the removal efficiency for iron and manganese is improved.

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1. Introduction

Cement kiln dust (CKD) is useless byproduct from the cement industry and a significant resource value for lime substituting. A. Salem *et al.* [1] investigated the adsorption capacity of hydroxyapatite and dust powders by measuring the lead concentration in the aqueous solution. It was found that, Weibull modulus of porous media is not affected by hydroxyapatite but the strength increases two times compared to the bed which is manufactured by using dust only. The influence of NaCl on mineral carbonation of CO_2 using cement material in aqueous solutions was studied by Hwanju Jo *et al.* [2]. It was found that, Ca leaching from ordinary Portland cement "OPC" in aqueous solution was enhanced by the presence of NaCl, as was the hydration of OPC, which promoted the formation of OPC-hydrated products such as calcium silicate hydrates C–S–H. After 24-h leaching, the C–S–H content in the reacted solid samples increased from18.5 to 45.5wt% as the NaCl concentration was increased to1.0M, but then decreased to 21.5wt% with further increase in the NaCl concentration.

Esawy [3] stated that the addition of coal to CKD at a hydraulic loading rate of 1.0 m^3/m^2h was effective in the removing of color, COD, BOD and heavy metals from textile industrial effluents and increasing of seed germination for treated effluents compared to CKD only. Allison [4]. studied the potential impact on settled water quality of using cement kiln dust (CKD), a waste by-product, to replace quicklime in the active treatment of acidic mine water. It was discovered that, treatment of mine water with the CKD-generated slurries removed over 98% of zinc and 97% of iron, the two soluble metals found in the highest concentrations in the untreated mine water. This was comparable to treatment with quicklime slurry at the 99% confidence level. Dinesh [5] reported that, adsorption is relatively new practice for the removal of metal ions/chromium. It was noticed that, some such materials have equal or more adsorption capacity than activated carbon. Nagwan Zaki [6] stated that, due to its high alkalinity, the leachate of CKD has high potential to be used for removing heavy metals, as hydroxides, from the solutions containing them. It was found that, for a waste solution containing 100 mg/l of Cu^{2+} ions the removal starts at a value of pH > 5.50, for a waste solution containing 100 mg/l Ni^{2+} ions the removal starts at a value of pH > 7 and for a waste solution containing 100 mg/l Zn^{2+} ions the removal starts at a value of pH > 7.30.

Mackie *et al.* [7] reported that, the main factor affecting the reactivity of CKD was found to be free lime content, and this could be used as an indicator of the potential for CKD material to be used in neutralizing acidic wastewaters. Anwar Ahmad *et al.* [8] studied the efficiency of CaO–CKD at doses of 1.5–20 g/l in batch experiments and it was found that, an average COD removal efficiency of 82.4% was achieved when a reactor was fed with 10 g/l CaO (COD as high as 70,390–75,480 mg/l) at an OLR of

12.5 kg-COD/m^3/ d under mesopHilic condition. A. Salem *et al.* [9] investigated the usage of cement kiln dust, zeolite, and bentonite as natural adsorbents in the industrial scale, for removal of lead from aqueous solution. It was concluded that, both of mechanical characteristics and sorption properties are optimized if 47.5 wt.% cement kiln dust, 32.5 wt.% zeolite, and 20.0 wt.% bentonite are added to adsorbent composition. Yan Feng *et al.* [10] studied the performance of water quenched slag particles "WQSP" for municipal wastewater treatment in a biological aerated filter. It was stated that, the WQSP reactor performed favorably for municipal wastewater treatment, in terms of chemical oxygen demand (COD_{cr}) and ammonia nitrogen (NH_3-N) removal at the conditions of water temperature ranging from 20 °C to 26 °C and DO ≥4mg/ L when hydraulic retention time ranged from 1 h to 5 h. Mostafa [11] discovered that, the traditional activated sludge process without primary settling tanks, and CKD dosage of 1 g/L is recommended for reuse of agricultural purposes at hot climate of temperature range of (30–35)°C and the traditional activated sludge process without primary settling tanks, and CKD dosage of 2 g/L is recommended for reuse of agricultural purposes at cold climate of temperature range of (15–20)°C. Jie Han, *et al.* [12] concluded that, experiments demonstrated the large treatment capacity of fixed-bed alipHatic polyamides "PA612" particles for the removal of EE2 from water on a continuous flow basis. With an empty bed contact time of 0.8-1.0 min, the column packed with 1.0 g PA612 particles removed EE2 from 24.1 L of 30 μg /L feed solutions to non-detectable levels.

An integrated performance assessment framework for water treatment plants was checked by Kejiang *et al.* [13]. coagulation/flocculation-sedimentation (unit1), filtration (unit2), and unit 1 unit 2 were constructed by integrating turbidity robustness indices. It was found that, specific relationship between turbidity and suspended solid concentration is used to transform suspended solid concentration to turbidity before the evaluation of the performance functions for unit 1 and unit 2. A field filtration method for the concentration and separation of suspended particulate matter from freshwater systems for subsequent determination of major elements (Si, Al, Ca, Fe, Mn, Mg, Na, K, P, Ti and S) was studied by Fredrik *et al.* [14]. It was found that, non-detectable concentrations of some elements are due to small differences between blank filter levels and the amounts of elements present on the filters after sampling. The calculated sums of main inorganic components, expressed as oxides, ranges between 94.0 and 98.0% ash weight.

Remediation technologies for heavy metal contaminated groundwater were investigated by Hashim *et al.* [15]. It was reported that, the most promising field of technology emerging in the last decade is the biological or biochemical techniques employing microbes and nutrients for bio-precipitation, enzymatic oxidations, bio-surfactants and sulphate reductions as heavy metal removal tools. Evaluation of the CO_2 sequestration capacity for coal fly ash using a flow-through column reactor was checked by Ho Young *et al.* [16]. It was noticed that, CO_2 sequestration capacity increased when the solid dosage was increased, whereas it was affected insignificantly by the CO_2 flow rate. A one M NH_4Cl solution was the most effective solvent, but it was not significantly different from de-ionized water or seawater. Wayne *et al.* [17] discussed the basic characteristics of CKD including current production and regulatory requirements. It was reported that, beneficial commercial uses are covering a wide variety of applications including agricultural soil enhancement, base stabilization for pavements, wastewater treatment, waste remediation, low – strength backfill and municipal landfill cover. An experimental study of the waste binder anhydrite in the solidification and stabilization process of heavy metal sludge was studied by Andres *et al.* [18]. It is concluded that, significant reductions are achieved in the metal leaching. Lead, cadmium and chromium mobility can be reduced near to 90%, depending on the processing variables: binder: waste ratio, particle diameter of the binder and water amount in the mixture; according to the toxicity characterization leaching procedure.

2. Material and Methods

A pilot plant has been designed and constructed in" El-Amerea Water Treatment Plant". Experiments have been carried out using different rates of filtration, different flow directions and different reactor depths as described hereafter.

2.1 Description of the Pilot Plant

The designed pilot plant is illustrated in figures (1) and (2) which consists of three circular plastic feeding tanks each of volume 100 liters. The three tanks are connected to each other with flexible tube of diameter of 2.54 cm to get total volume of 300 liter. This volume will be enough to run the experiment for some hours using the applied rates of filtration in this study. The dimensions of each tank are 80.0cm height and 44.0 cm diameter. The feeding tanks are connected with a constant head tank by flexible tube of diameter 2.54 cm. The dimensions of the constant head tank are 40.0 cm length * 14.0 cm width * 35.0 cm height. The function of the constant head tank is to fix the water head on the filters, in order to regulate the rate of flow.

The constant head tank is connected with two plexi-glass pipes by two flexible tubes of diameter 1.60 cm. The inner diameter of each plexi-glass pipe is 9.60 cm and the height is 100 cm per each pipe. A polyethylene valve of diameter 1.25 cm is fitted on the outlet of the feeding tanks. Then three valves of diameter 1.25 cm are fitted on the constant head tank which joining the constant head tank with the two columns. Two 1.25 cm valves are fitted on the outlets of the two plexi-glass pipes to control the rate of flow. Three ports of diameter 1.25 cm (for sampling) was distributed along the height of the filter, the first one was at depth 10 cm from the end of column, the second one was at depth 55 cm from the inlet valve and the third one was at 90cm from the inlet valve. These ports were constructed in order to study the effect of depth of filter media in the removal efficiency of metals. A wire mesh was used inside the columns to prevent the CKD from escaping outside the columns and for the first 10cm of column height was filled with sand which is used in the filters in the treatment plant. The plexi glass columns have an identical gross volume of 6.50 liter and effective volume of 2.20 liter. The cross sectional are of the wired mesh depth =24.62 cm^2.

Feeding pump of model "jet 100 A" was constructed in the inlet of feeding tanks. The designed flow rate of this self-priming pump was 40.0 liter/min and the horsepower of the concerned pump was 1.0 HP and the input power =0.75 kw . The maximum head of the concerned pump was 35 meters and the number of revolutions was 2850 rpm. And the suction head was 9 m. The inlet and outlet of the concerned pump was 2.54 cm. Two flexible tubes of diameter 2.54 cm were conducted with the pump. The first one was used for the suction of water from the raw water sump in the low lift pump building and the other was connecting the pump with the inlet of the feeding tanks (delivery). Non-return valve of diameter 2.54 cm was installed in the inlet of the suction flexible tube of diameter 2.54 cm.

2.2 Material

The initial concentration of iron was raised by adding Ammonium iron (II) sulfate hexahydrate, $(NH_4)_2Fe(SO_4)_2.6H_2O$ and the molecular weight = 392.14. Manganese concentration in raw water was raised by adding Manganese (II) SulpHate -I- hydrate $MnSO_4.H_2O$ and the molecular weight = 169.10 to increase the initial concentrations to about 10 mg/l. A Whatman filter paper circle equiv no.1 of size 150 mm diameter was used before measuring the concentration of iron and manganese for all samples. The first 10cm of the column was filled with sand which is used in the filter media in Alamerea water treatment plant and then the CKD was filled the required depth of filter media. Different CKD depth, rates of filtration and flow techniques were applied. There were some deviations during experimental work.

2.2.1 Cement Kiln Dust"CKD"

The source of the cement kiln dust was El-Nahda cement industry in Qena and the composition of the used CKD was as follows:

Table 1. Typical Composition of Cement Kiln Dust. Wayne *et al.* [17]

constituent	% by weight	constituent	% by weight
$CaCO_3$	55.5	Fe_2O_3	2.1
SiO_2	13.6	KCl	1.4
CaO	8.1	MgO	1.3
K_2SO_4	5.9	Na_2SO_4	1.3
$CaSo_4$	5.2	KF	0.4
Al_2O_3	4.5	Others	0.7

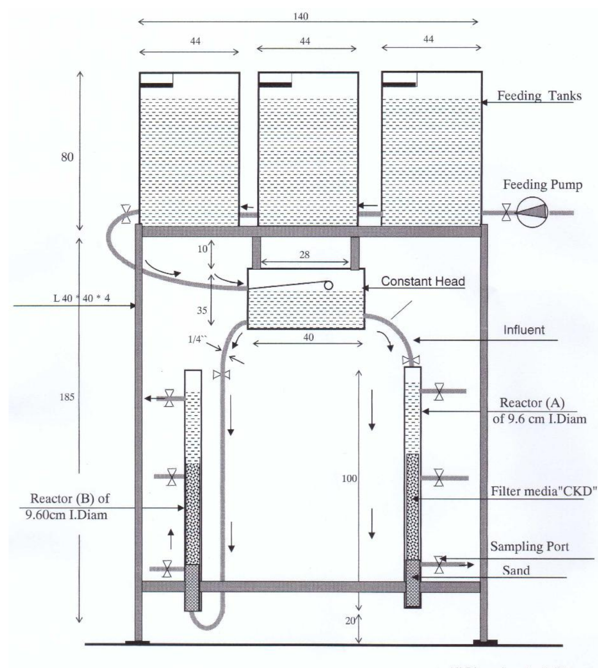

Fig. 1. A Schematic Sketch for The Experimental Setup

3. Results

The first run was conducted through CKD depth = 60cm and the rate of filtration was 100 m^3/m^2.day. The obtained results were illustrated in table. 2.

Fig.2. A photo for the Pilot Plant

Table. 2. Concentrations of iron and manganese (R.O.F= 100 m^3/m^2.day - CKD depth = 60cm- fixed bed)

	Before filtration	After 1 hour	After 3 hours	After 5 hours	After 7 hours
Fe "mg/l"	9.9	0.015	0.56	udl	udl
Mn "mg/l"	10.2	udl	8.5	udl	udl
PH	7.4	11.25	8.17	11.12	11.12
Conductivity- µs/l	490	1400	574	1190	1855
TDS "mg/l"	327	933	383	793	1237

The second run was conducted through CKD depth = 60cm and the rate of filtration was 200 m^3/m^2.day. The obtained results were presented in table.3.

Table.3. Concentrations of iron and manganese (R.O.F= 200 m^3/m^2.day - CKD depth = 60cm- fixed bed)

	Before filtration	After 1 hour	After 3 hours	After 5 hours	After 7 hours
Fe "mg/l"	9.9	0.015	0.046	0.62	0.02
Mn "mg/l"	10.2	udl	udl	10.2	udl
PH	7.4	10.20	9.92	8.32	11.43
Conductivity- µs/l	490	1152	936	624	3270
TDS "mg/l"	327	768	624	416	2180

- The third run was conducted through CKD depth = 60cm and the rate of filtration was 250 m^3/m^2.day. The obtained results were as follows and the initial concentration of iron and manganese was as follows:

Table.4. Concentrations of iron and manganese (R.O.F= 250 m^3/m^2.day - CKD depth = 60cm- fixed bed)

	Before filtration	After 1 hour	After 3 hours	After 5 hours
Fe "mg/l"	11.0	0.41	0.088	udl
Mn "mg/l"	10.30	0.90	8.11	udl
PH	8.03	8.57	8.36	11.27
Conductivity-" µs/l "	487	1160	858	1811
TDS "mg/l"	325	773	572	1207

- The fourth run was conducted through CKD depth = 60cm and the rate of filtration was 300 m^3/m^2.day. The obtained results were as follows and the initial concentration of iron and manganese was as follows:

Table.5. Concentrations of iron and manganese (R.O.F= 300 m^3/m^2.day - CKD depth = 60cm- fixed bed)

	Before filtration	After 1 hour	After 3 hours	After 5 hours
Fe "mg/l"	11.0	0.355	0.066	udl
Mn "mg/l"	10.30	6.76	10.27	udl
PH	8.03	8.36	8.14	11.25
Conductivity-" µs/l "	487	649	615	2340
TDS "mg/l"	325	433	410	1560

The iron removal efficiencies of the applied rates of filtration mentioned above is depicted in figure.3. and the applied technique was fixed bed flow and the used depth was 60cm.

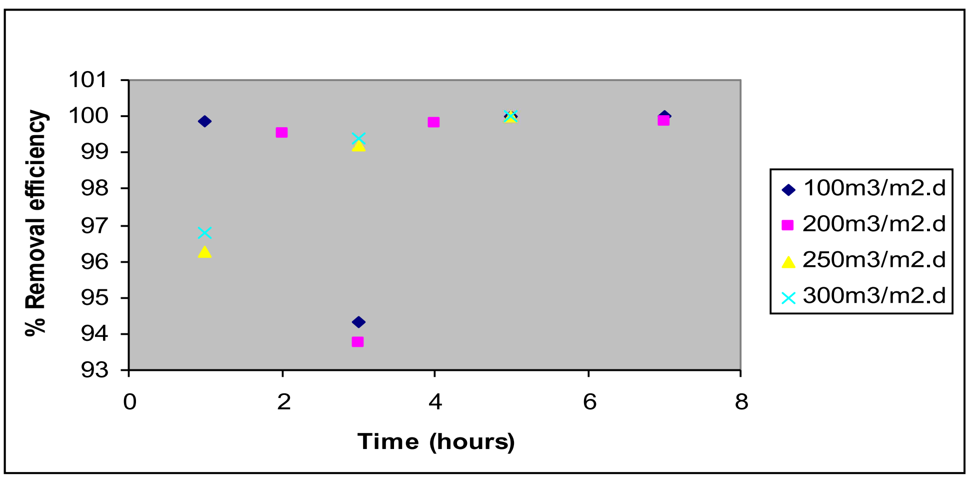

Fig.3. Iron removal efficiency for different rates of filtration.

The Manganese removal efficiencies of the applied rates of filtration mentioned above is depicted in figure.3. The applied technique was fixed bed flow and the used depth was 60cm.

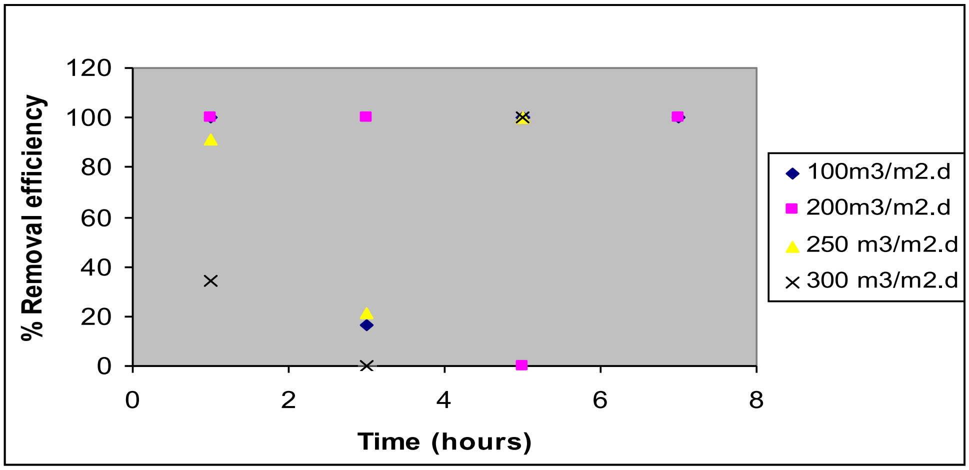

Fig.4. Manganese removal efficiency for different rates of filtration.

Different depth was applied the first one was 60cm and the second was 40cm and the third was 20cm and the applied rate of filtration was 200 m^3/m^2.day. The obtained results were as follows for CKD depth = 20cm:

Table 6. Concentrations of iron and manganese (R.O.F= 200 m^3/m^2.day - CKD depth = 20cm- fixed bed)

	Before filtration	After 1 hour	After 3 hours	After 5 hours
Fe "mg/l"	8.0	1.07	udl	0.19
Mn "mg/l"	9.12	7.33	7.09	9.12
PH	6.7	7.9	8.17	7.46
Conductivity-" µs/l "	541	632	1254	650
TDS "mg/l"	361	421	836	433

The obtained results were as follows for CKD depth = 40cm:

Table 7. Concentrations of iron and manganese (R.O.F= 200 m^3/m^2.day - CKD depth = 40cm- fixed bed)

	Before filtration	After 1 hour	After 3 hours	After 5 hours
Fe "mg/l"	8.0	udl	udl	udl
Mn "mg/l"	9.12	0.02	5.95	udl
PH	6.7	10.13	8.13	11.01
Conductivity-" µs/l "	541	1432	997	6130
TDS "mg/l"	361	955	665	4087

The iron removal efficiency for different CKD depth was demonstrated in figure 5.The applied rate of filtration was 200m^3/m^2.day and the flow technique was fixed bed.

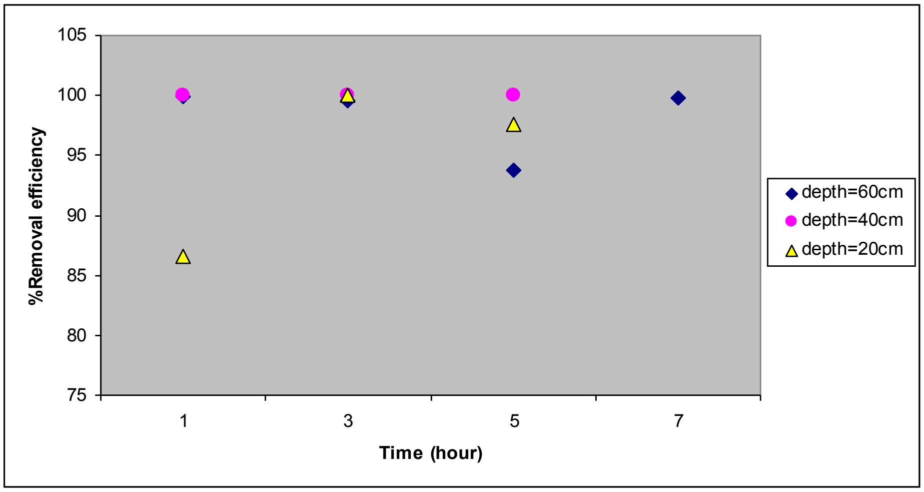

Fig.5. Iron removal efficiency for different CKD depths.

The Manganese removal efficiency for different CKD depths was demonstrated in figure 5.The applied rate of filtration was 200m^3/m^2.day and the flow technique was fixed bed.

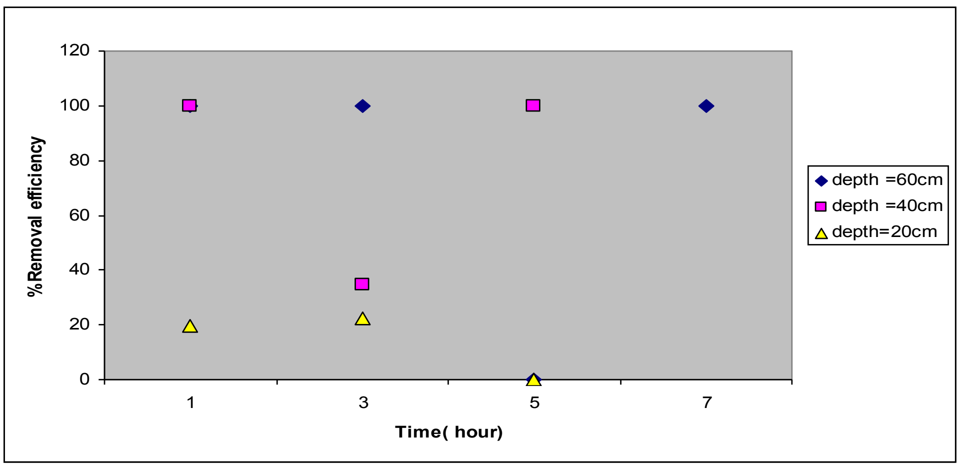

Fig.6. Manganese removal efficiency for different CKD depths.

Different flow techniques were applied the first one was fixed bed and the second was fluidized bed and the applied rate of filtration was 200 m^3/m^2.day. The obtained results were as follows for CKD depth = 40cm:

Table.8. Concentrations of iron and manganese (R.O.F= 200 m^3/m^2.day - CKD depth = 40cm- fixed bed)

	Before filtration	After 1 hour	After 3 hours	After 5 hours
Fe "mg/l"	10	0.86	0.67	udl
Mn "mg/l"	12	10.80	10.10	udl
PH	7.19	7.22	7.42	9.28
Conductivity-" µs/l "	568	579	568	577
TDS "mg/l"	379	386	379	385

Different flow techniques were applied the first one was fixed bed and the second was fluidized bed and the applied rate of filtration was 200 m^3/m^2.day. The obtained results were as follows for CKD depth = 40cm:

Table.9. Concentrations of iron and manganese (R.O.F= 200 m^3/m^2.day - CKD depth=40cm- fluidized bed)

	Before filtration	After 1 hour	After 3 hours	After 5 hours
Fe "mg/l"	10	0.62	0.67	udl
Mn "mg/l"	12	7.00	7.80	udl
PH	7.19	7.88	7.81	10.58
Conductivity" µs/l"	568	1133	781	1333
TDS "mg/l"	379	755	521	889

The iron removal efficiency for depth=40cm and rates of filtration =200m^3/m^2.day. Different flow techniques were applied as depicted in figure 7.

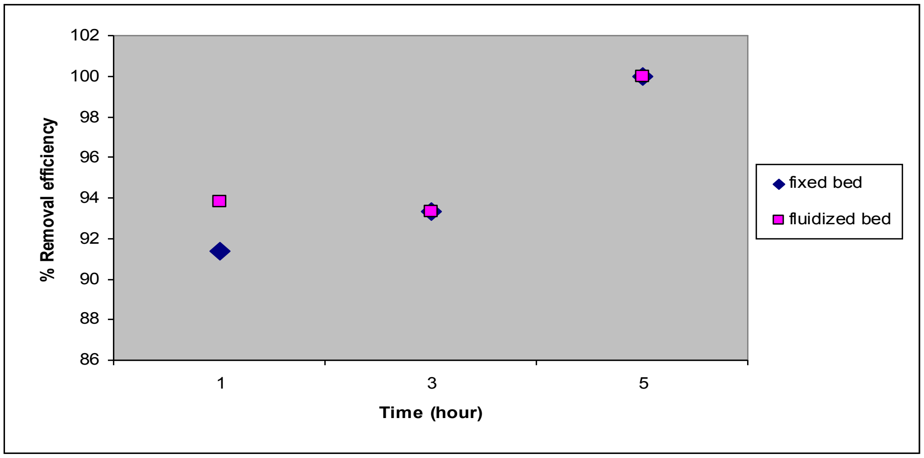

Fig.7. Iron removal efficiency for different flow techniques.

The manganese removal efficiency for depth=40cm and rates of filtration =200m^3/m^2/day. Different flow techniques were applied as depicted in figure 7.

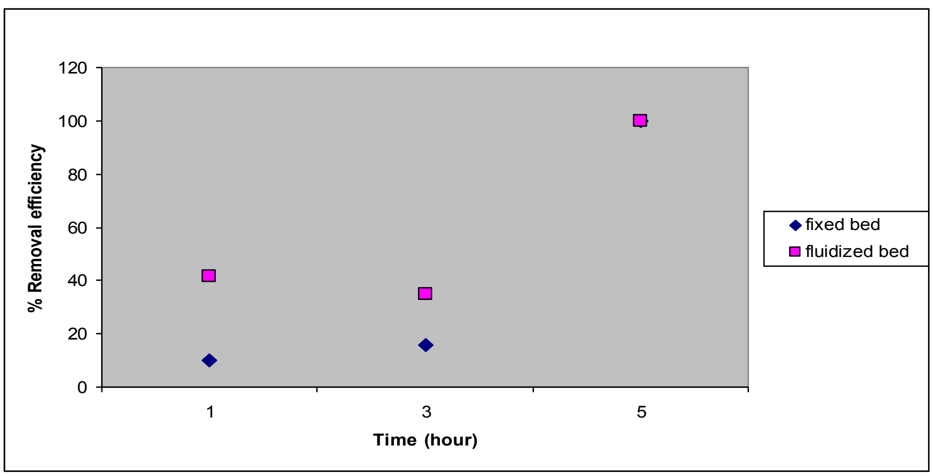

Fig.8. Manganese removal efficiency for different flow techniques.

Jar test was investigated in order to optimize the usage of CKD as a coagulant for removing iron and manganese. Different doses were added to raw water as a primary coagulant. The obtained results were as follows:

Table.10. CkD doses as a primary coagulant

Sample	CKD dose "mg/l"	PH	Cond µs/l	Fe "mg/l"	Mn "mg/l"
Raw water	-	7.22	535	10	10
First	20	7.62	536	0.26	9.68
Second	40	7.61	538	0.30	9.46
Third	60	7.69	549	0.32	9.56
Fourth	80	7.84	547	0.35	9.35
Fifth	100	8.11	554	0.41	9.23
sixth	120	8.22	557	0.38	9.13

The removal efficiencies for iron and manganese were plotted in figure. 9.

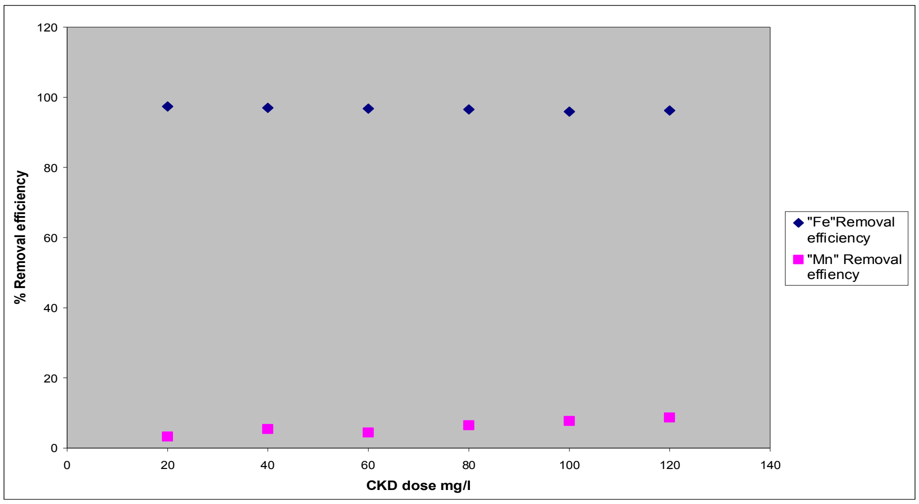

Fig.9. Iron and Manganese removal efficiency for different CKD doses.

4. Conclusion

Available findings may be summarized as follows:

1- Rate of filtration 200m^3/m^2.day can be used and is found to be more suitable for the cement kiln dust particles properties.

2- 40 cm CKD depth is enough for removing iron and manganese from raw water.

3- Fluidized bed is better more than fixed bed technique.

4- CKD was used as a primary coagulant with different doses ranged from 20 mg/l to 120 mg/l. It was observed that, CKD was effective for iron removal but for manganese was not efficient.

5- Results demonstrated that, 20 mg/l of CKD is sufficient for iron removal.

6- It was noticed that the when the pH was raised the removal efficiency for iron and manganese is improved.

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