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Assessment of Physico-chemical Processes for Treatment and Reuse of Greywater

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THE PRESENT study deals with real greywater that was collected from five flats and connected to a pilot plant. The research study aims at evaluation of greywater treatment and reuse using diverse phico-chemical treatment process including sedimentation, coagulation/flocculation and Fenton`s reaction. The study includes the evaluation of different settling times using two successive sedimentation tanks that received raw greywater. The chemical coagulation phase includes lime and lime aided with ferric chloride as well as advanced oxidation (as Fenton's reaction). The experimental method involves monitoring of specific water quality constituents, under varying operating conditions, at different sedimentation periods and different chemicals doses to reach the sustainable approach. Greywater treatment was examined first in batch experiments to determine the optimum operating conditions including: the settling time, the dose of lime (CaO), ferric chloride ($FeCl_3$), and Fenton's reaction [$Fe_2(SO_4)_3.H_2O_2$]. The obtained optimum conditions were implemented throughout the pilot plant investigation.

The pilot plant study was performed at a settling time of 3.0 hr, the removal rates shifted from the initials 64.5, 30.1, 19.4 and 31.7% to 71.3, 25.5, 29.6 and 49.1% for the TSS, COD, BOD_5 and oil & grease, respectively. Such treatment was not sufficient to reach the characteristics of non-restricted reuse. By increasing the settling time to 4.5 hr, better removal efficiency could be achieved namely; 66.5%, 40.3%, 38.5%, and 50.2%, successively. To enhance the treatment efficiency of the above system; lime was added at 160 mg/l where the characteristics of the final effluent could cope with the permissible level of the 2nd group (secondary wastewater treatment) for irrigation reuse according to the "Egyptian Guideline". Combination of chemical treatment using lime (160 mg/l) aided with ferric chloride (100 mg/l) with sedimentation (4.5 hours) was carried out. The obtained results showed that the removal rates of TSS, COD, BOD and oil & grease enhanced to 94.9, 91.8, 94.2 and 97.2%, successively. *The E. coli* count and the number of cells or eggs of Nimatoda in the final effluent reached 100/ml and 1 count/l, respectively. The final effluent could cope with the permissible level, 1st Class (advanced wastewater treatment), for non-restricted water

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reuse according to the "Egyptian Guideline for wastewater reuse". Present study proves that chemical coagulation could successfully approach the objectives of treatment while mutually saves space, energy and labors.

Keyword: Greywater treatment, Water reuse, Sedimentation, Chemical coagulation, Lime, Ferric chloride and Fenton's reaction.

Treatment of greywater can range from simple coarse filtration(1) to advanced biological treatment(2). Previous studies suggested that biological processes should be preferred due to the high levels of organics in the water(3,4) including constructed wetland(5,6). The major difference between different technologies is the level of suspended solids and microorganism removal. In comparison, direct physical processes are common at very small scale for the removal of suspended solids, but are less effective for organics removal (4,7).

Most greywater treatment plants include a one or two-step septic-tank for pre-treatment(2). Currently, most greywater treatment systems installed are based on septic tanks in combination with constructed wetlands(8,9). The greywater treatment needs both physical and biological processes for removal of particles, dissolved organic-matter and pathogens(10,11). Only few studies on chemical treatment of greywater are available. On the other hand, chemical coagulation proved to be very effective in the removal of suspended solids and precipitation of heavy metals(12,13). Therefore, combination of chemical treatment with sedimentation could be very effective. An important feature of such combination is the advantage of operating at a short hydraulic retention time (HRT) as well as effective sludge precipitation and the possibility to combine the removal of BOD / COD(14,15).

Using coagulation and sedimentation improves the removal of the colloidal suspended solids from wastewater(12). The coagulants used included aluminium sulfate, ferric sulfate, lime, and/ or ferric chloride. Alum and ferrous sulfate showed better turbidity removal than that of the lime and ferric chloride. A mixture of alum and ferric chloride could achieve better removal of all the colloidal suspended solids. It was found that the aeration of the coagulated and settled samples improved the COD removal efficiently than the samples that were not coagulated by about 41%. (12,16,17).

Recently, ferric chloride was tested as coagulant for the treatment of wastewater using bench- scale investigation(12,18). The study proved that 38% decrease of the organic load was achieved, where the effluents were low in organic content, suspended matter and colloids(19).

Aluminium sulphate and ferric chloride were used as coagulant and coagulant aid. The COD and chromium were removed mainly through coagulation: 38–46% removal of suspended solids, 30–37% removal of total COD from settled tannery wastewaters and 74–99% removal of chromium at an initial concentration of 12 mg/l. The optimum coagulant dosage was 800 mg/l at pH around 7.5 [20].

Rubi *et al*. (2009)[21] studied the treatment of wastewater discharged from four car washing water. The study included sedimentation and coagulation. The effects of the coagulants Servical P (aluminium hydroxyl chloride), Servican 50 (poly-diallyldimethyl ammonium chloride), aluminium sulphate and ferric chloride were evaluated. The achieved removal using sedimentation was 82%, 88% 73% and 51% for oils, total suspended solids, COD and turbidity, respectively. In the treatment by coagulation they achieved average efficiencies nearly to 74% for COD removal, greater than 88% in the case of total suspended solids removal and 92% in the case of turbidity and except the performance of Servican 50 greater than 90% in oil removal.

Some of the additional advantages of employing ferric or aluminium salts in wastewater treatment are: precipitation of sulphur compounds, easier sludge dewatering and increased efficiency of pollutants elimination. Meanwhile, reduction in energy consumption that is used for the biological process was also achieved [22]. The disadvantage is the relative increase in the sludge volume. In addition, large amounts of chemicals should be transported to the treatment location and polymers used can be expensive [23].

It was found that Fenton process using ferrous sulphate could remove between 45% and 49% of the COD in low-range greywater. The photo-Fenton process achieved 83% COD removal [24].

This work aims to increase the efficiency of the sedimentation process by employing chemical treatment in combination with settling system. The chemical treatment includes coagulation (lime only, ferric chloride aided with lime) or advanced oxidation (Fenton's reaction) followed by sedimentation. The experimental method involves monitoring of specific water quality constituents under varying operating conditions and correlating between the different treatments systems. The final effluent could be discharged safely to the waterways or to be reused for irrigation according to the EEAA [25].

Material and Methods

Source of raw greywater

Real greywater is the subject of the present study. To obtain a real greywater, municipal wastewater was separated from the origin into Black (B), Grey (G) and Yellow (Y) water as segregated and collected from one house across the Training Demonstration Centre (TDC) site in the National Research Centre (NRC), Cairo, Egypt. One side of this house that consists of five apartments is presently connected to the TDC site as separated B, G and Y water manholes. The collected greywater (G) includes wastewater from baths, showers, handwash basins, washing machines, dishwashers and kitchen sinks. The schematic diagram of the greywater route to the pilot-plant is illustrated in Fig. 1.

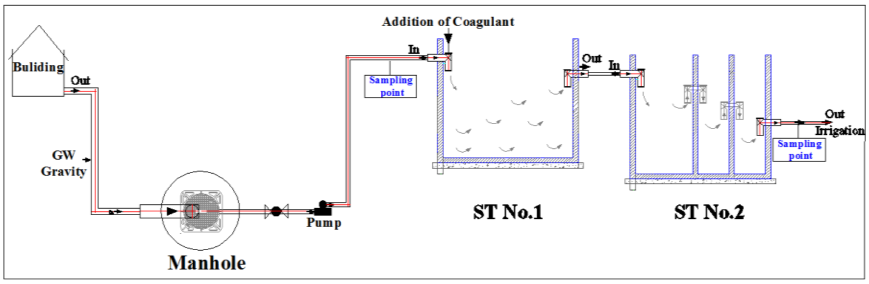

Fig. 1. The schematic diagram of the greywater route to the pilot-plant and the treatment system (side view).

The present study was carried out in both bench- and pilot plant scales (Fig. 2).

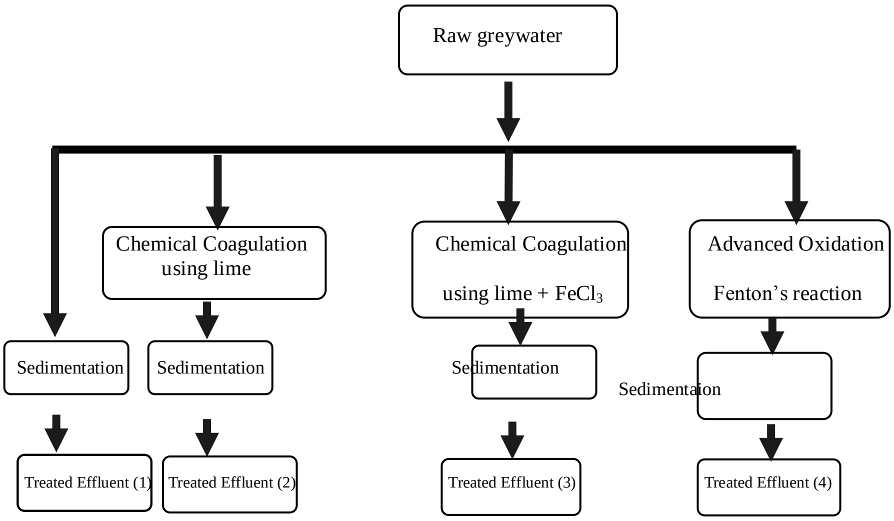

Fig. 2. Schematic diagram of the treatment system.

Bench-scale investigation

The experiments were conducted in a jar-test apparatus at room temperature. Batch reactors consist of flash mix at speed of 300 rpm, flocculation for 20 rpm followed by settling for 30 min.

Determination of optimum chemical coagulant dose

The examined chemical coagulants were lime and lime aided with ferric chloride. Determination of the lime optimum dose was carried out. The examined lime dose ranged from 5 to 200 mg/l. Further, an investigation was carried out to determine the optimum dose of ferric chloride to the predetermined lime optimum dose. The examined ferric chloride dose ranged from 10 to 120 mg/l.

Determination of optimum advanced oxidation dose

Fenton's reaction as presented by hydrogen peroxide and ferric sulfate was examined. The advanced oxidation consists of ferric sulfate dose ranged from 50 to 800 mg/l, whereas examined hydrogen peroxide dose ranged from 5 to 130 mg/l.

Pilot -plant continuous system

The treatment train is illustrated in the schematic diagram (Fig. 2). Four treatment approaches were investigated as follows:

The 1st approach is settling the raw greywater in the settling tank (Fig. 3) in absence of any chemicals,

the 2nd approach is receiving the raw greywater, thereafter adding the predetermined lime dose followed by settling,

the 3rd approach is receiving the raw greywater, thereafter adding the predetermined lime dose and ferric chloride doses followed by settling,

the 4th approach is receiving the raw greywater, thereafter adding the predetermined advanced oxidation (Fenton's reaction) followed by settling.

Sedimentation tank

Two-step process of successive sedimentation tanks was applied as pre-treatment phase to remove larger particles, hair, oil and grease (Fig. 3). Effluent of the sedimentation tanks was then directed to irrigation purposes (Fig. 1).

The two sedimentation tanks are made of polyvinyl chloride (PVC) with a working volume of 0.7 m^3 each (Fig. 3). The dimension of each tank is: 1.00 m height, 0.90 m width and 1.00 m length. The reactor as a rectangular basin is raised from the ground surface about four meters. The first tank consists of three chambers separated with baffles at a distance of 0.4m, 0.3m, and 0.3 m with 0.9 m in width and 1.00 m in depth (Fig. 3-side view). The outlet is then directed to the second sedimentation tank (Fig. 3 top view). These chambers provide the quiescent condition necessary for the settling process.

The average flow rate of the greywater influent to the sedimentation tank is 225 L/ hr with a Surface Overflow Rate (SOR) of about 2.5 m /hour and a retention time of 90 min. This study included the examination of the removal efficiency at different settling times; namely 1.5, 3.0 and 4.5 hr.

The physical and chemical characteristics of the raw greywater were determined on weekly basis. Meanwhile, the physical and chemical characteristics of the examined greywater before and after treatment by batch and pilot-plant studies were carried out according to the Standard Methods of American Public Health Association [26].

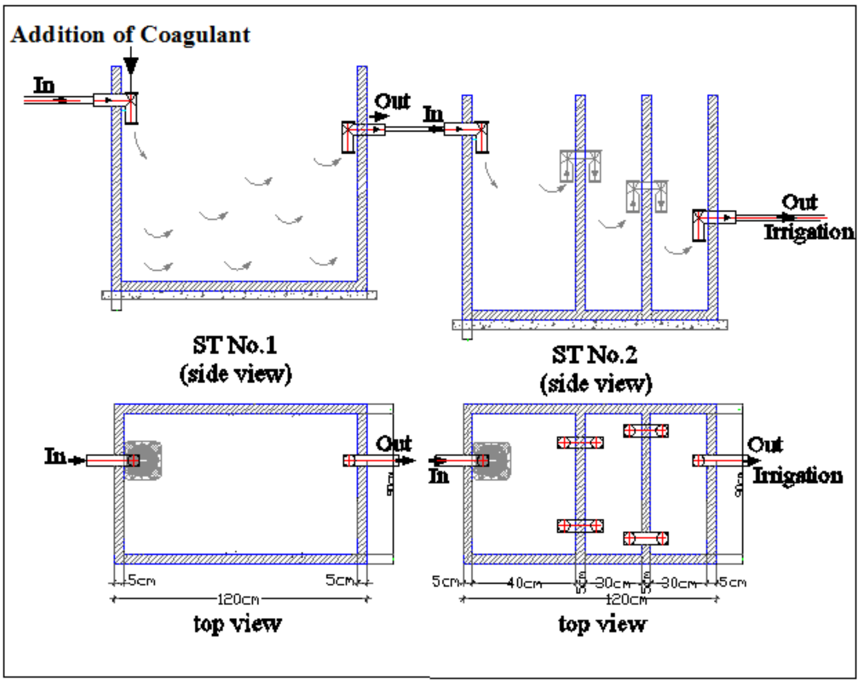

Fig. 3. Schematic diagram of the settling (sedimentation) tanks No.1 and No.2 (side view and top view) .

Results and Discussion

Physical and chemical characteristics of raw greywater

The characteristics of the raw greywater are given in Table 1. The results show that the concentrations of COD, BOD_5 and oil & grease are within the high level range. However, the dissolved oxygen is within the low level whereas pH is at the neutral level. By correlating the characteristics of the raw greywater (Table 1) with the permissible limits (Table 2) it can be seen that such greywater is allowed to be used for irrigating woody trees according to the Egyptian regulation of the "Egyptian Environmental Affairs Authority"[25] without any treatment as 3rd class irrigation water (Table 2).

TABLE 3. Bench-scale study on the effect of H_2O_2 dose on the treatment of raw greywater at constant ferrous sulfate dose (130 mg/L).

Parameter	Number of samples	Raw greywater Con.	H_2O_2 dose											
			50 mg/l		100 mg/l		200 mg/l		400 mg/l		600 mg/l		800 mg/l	
			Con.	% R	Con.	% R	Con.	% R	Con.	% R	Con.	% R	Con.	% R
Temperature °C	5	28.52	28.78	---	28.8	---	28.83	---	28.93	---	29.02	---	29.11	---
pH	5	6.81	10.2	---	10.3	---	10.4	---	10.38	---	10.35	---	10.3	---
TSS (mg/l)	5	70	18	74.29	10.3	85.29	68	2.86	61	12.86	50	28.57	46	34.29
COD (mgO_2/l)	5	336	113	66.37	43	87.20	187	44.35	196	41.67	212	36.90	222	33.93
BOD_5 (mgO_2/l)	5	246	164	33.33	103	58.13	131	46.75	134	45.53	142	42.28	153	37.8
Oil & Grease (mg/l)	5	86	14	83.72	22	74.42	34	60.47	27	68.6	16	81.40	12	86.05

Con. = concentration, % R = Percentage of removal

TABLE 5. Pilot plant study on the average characteristics of greywater after settling for 3 and 4.5 hr in absence of chemicals.

Parameter	Number of samples	Raw greywater concentration (average)	Settling Tank (3.0 hr)		Settling Tank (4.5 hours)		Permissible limits 2nd group for (secondary treatment)*
			Concentr-ation (average)	Removal %	Concenr-ation (average)	Rem-oval %	
TSS (mg/l)	7	126.6	44.9	64.5	36.3	71.3	40
COD (mg/l)	7	470.2	375.8	20.1	350.5	25.5	80
BOD (mg/l)	7	346.2	279.1	19.4	243.8	29.6	40
Number of cells or eggs of Nimatoda (Count/l)	7	---	---		---	---	1
E.Coli count (100/ml)	7	ND	ND	----	ND	---	1000
Oil & grease (mg/l)	7	124.8	85.3	31.7	63.5	49.1	10
SAR (%)	7	20.87	19.69	5.62	19.09	8.53	20

*Egyptian regulation: (Reference No. 25)
ND = not detected

TABLE 6. Characteristics of greywater after chemical coagulation with lime followed by settling for 3.0 and 4.5 hr

Parameter	Number of samples	Raw greywater concentration (average)	Addition of lime (160 mg/l) followed by settling for (3.0 hr)		Addition of lime (160 mg/l) followed by settling for (4.5 hr)		Permissible limits 2nd group for (secondary treatment)*
			Concentration (Average)	Removal %	Concentration (average)	Removal %	
TSS (mg/l)	7	101.33	24.67	75.66	19.77	80.49	40
COD (mg/l)	7	399.67	126	68.47	111.5	72.10	80
BOD (mg/l)	7	256	78.67	69.27	63.7	75.12	40
Number of cells or eggs of Nimatoda (Count/l)	7	ND	ND	ND	ND	ND	1
E. *Coli* count (100/ml)	7	---	---	---	---	---	1000
Oil & grease (mg/l)	7	163.67	24.83	84.83	18.5	88.70	10
SAR (%)	7	20.04	17.9	10.68	16.5	17.66	20

*Egyptian regulation: Reference No. 25
ND = not detected

1.

TABLE 7. Characteristics of greywater after chemical coagulation with lime in combination with ferric chloride followed by settling for 3.0 and 4.5 hr*.

Parameter	Number of samples	Raw Greywater concentration (Average)	Addition of lime (160 mg/l) and ferric chloride (100 mg/l) followed by settling for (3.0 hr)*		Addition of lime (160 mg/l) and ferric chloride (100 mg/l) followed by settling for (4.5 hr)*		Permissible limits 3rd group for (advanced treatment)**
			Concentration (Average)	Removal %	Concentration (Average)	Removal %	
TSS (mg/l)	7	111.67	7.33	93.43	5.75	94.85	20
COD (mg/l)	7	434.33	79.67	81.66	35.67	91.79	40
BOD (mg/l)	7	309.33	38	87.72	18	94.18	20
Number of cells or eggs of Nimatoda (count/l)	7	ND	ND	ND	ND	ND	1
E.Coli count (100/ml)	7	---	---	---	---	---	100
Oil & greaser (mg/l)	7	177	9.5	94.63	5	97.17	5
SAR (%)	7	23.79	21.4	10.02	19	20.13	20

*Dose of lime = 160 mg/l, dose of ferric chloride = 100 mg/l
**Egyptian regulation: Reference No. 25
ND = not detected

Addition of lime in combination with ferric chloride followed by settling

Addition of lime in combination with ferric chloride at the predetermined optimum doses (160 mg/l lime and 100 mg/l $FeCl_3$) was examined followed by settling for 3.0 hr. The removal rate reached 93.4, 81.6, 87.7 and 94.6% for TSS, COD, BOD and oil & grease, respectively (Table 7). The characteristics of the final effluent could cope with the permissible limits of the 2*nd* class water reuse [(25)].

By increasing the settling time to 4.5 hr, further increase in the removal rates was remarkably achieved (Table 7). The removal rates reached 94.9, 91.8, 94.2 and 97.2% for TSS, COD, BOD and oil & grease, successively (Table 7). The characteristics of the final effluent decreased to 5.8, 35.7, 18.0 and 5.0 mg/l, respectively. It is worth noting that the characteristics of this final effluent are within the permissible level of the 1st class (advanced treated wastewater) as a sustainable approach for non-restricted water reuse according to the "Egyptian Guideline" [(25)].

Conclusions

1. When the kitchen outflow water is included in greywater then relatively high amount of oil & grease as well as increasing amount of COD and BOD is expected. Therefore, it is recommended to avoid connecting the kitchen outflow to the greywater.
2. Increasing the settling time remarkably increases the achieved removal rate of the pollution parameters.
3. Addition of lime associated with ferric chloride to the raw greywater could effectively enhance the settling process.
4. When 160 mg/l lime was added to the raw greywater followed by 3.0 hr settling time improvement was achieved. The characteristics of the final effluent nearly reached the permissible level 2*nd* class (secondary wastewater treatment) for irrigation reuse according to the "Egyptian Guideline".
5. Using ferric chloride at a level of 100 mg/l aided with lime dose of 160 mg/l followed by 4.5 hr settling time, the final effluent could cope with the permissible level of 1*st* class (advanced treated wastewater) as non-restricted water reuse according to the "Egyptian Guideline". It is worth mentioning that iron is precipitated as sludge and remaining amount of iron is limited. On the other hand, iron is considered a nutrient element to soil and plant at low concentration.
6. It has been concluded that chemical coagulation could successfully approach the objectives of the suggested treatment process. Therefore, it saves any further treatment (*i.e.* saves the burden of space, energy or labor).
7. Greywater reuse presents a potential option for water demand management that can contribute to the reduction of freshwater consumption for irrigation, particularly in the remote and decentralized areas.

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المعالجه الطبيعيه والكيميائيه للمخلفات السائله الرماديه لاعادة استخدامها

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الدراسه الحاليه تعامل مع مياه رماديه حقيقيه تم تجميعها من منزل مقابل للموقع التجربه النصف صناعيه في المركز القومي للبحوث. تشمل الدراسه تقييم اختلاف وقت الترسيب باستخدام احواض الترسيب لاستلام المياه الرماديه الخام. في هذه الدراسه ، استخدم التخثر الكيميائي بالشب فقط ثم الشب مع كلوريد الحديديك بجرعات مختلفه ، كما تم اختبار الاكسده المتقدمه (Fenton’s reaction).

تمت الدراسه معمليا ثم تطبيقيا على مستوى نصف صناعي ، حيث اثبتت الدراسه المعمليه ان زياده وقت الترسيب الى 4.5 ساعات كان افضل فى ازالة كل من

66.5 %, 40.3 % , 38.5% , and 50.2 % , for the TSS, COD, BOD_5 من

and oil & grease على التوالى عند استخدام الشب وجد ان افضل تركيز 160ملجم لكل لتر، أفضل تركيز كلوريد الحديديك مع الشب تركيز 100 ملجم لكل لتر، بتطبيق التراكيز على التجربه النصف صناعية عند ترسيب 4.5 ساعات توصل الى ازالة الحددات TSS,COD, BOD and oil & grease enhanced to 94.9, 91.8, 94.2 and 97.2%,بنفس الترتيب .

كانت خواص المياه الرماديه المعالجه مطابقه للكود المصري في الحدود المسوح بها لاعادة استخدام المياه المعالجه بدون قيد او شرط . كما اثبتت الدراسه ان استخدام التخثر الكيمائي هي طريقه ناجحه للوصول الى معالجه متكامله, كما انها توفر مساحة ارض وطاقه وعماله في حالة استخدام طرق اضافيه بديله.