Upgrading of An Eighty Years Old Water Treatment Plant- A Case Study

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ABSTRACT

An existing water treatment plant, which was built in 1921 have been upgraded in 2001. The plant has been upgraded by increasing its capacity and efficiency. The capacity of the plant was 100 l/s. The plant comprises plain sedimentation tanks, rapid sand filters and ground tank. The existing units were not functioning properly. The plant capacity has been increased to 300 l/s after upgrading. The plant has been enhanced by employing new available technologies on the existing units. The sedimentation tanks were upgraded by dividing each tank into two compartments: the first one is assigned for flocculation by using contact flocculation media and the second, is assigned for sedimentation by using inclined plate settlers. In addition to rehabilitation of the existing sedimentation tanks, new rapid sand filters have been constructed. The results showed that the effluent turbidity was 0.4 NTU on average. The study revealed that the performance of the plant has been improved significantly. The total cost of the upgrading was in the vicinity of 9 million Egyptian pounds while a newly constructed plant with the same capacity, cost around 70 to 80 million Egyptian pounds at that time.

Keywords: Old treatment plant; Upgrading; Contact flocculation; Plate settlers

1. INTRODUCTION

The rapid population growth as well as urbanization in Egypt increases the demand on efficient water treatment plants and distribution networks. On the other hand, expansion of an existing water treatment plant using conventional technologies may require a large area of land which is mostly unavailable at the old Egyptian cities. Therefore, upgrading of the old water treatment plants may become an important alternative to meet the population demand and the regulatory standards. This case study illustrates the solutions made for expanding and upgrading of an old water treatment plant located at Kafr El-Sheikh city. The plant was constructed in 1921 with a capacity of 100 l/s, including plain sedimentation and rapid sand filtration for treating high turbid water. Most facilities of the plant were not functioning properly with overall poor performance. In year 2001, the plant was not working for the last two years and the challenge was to upgrade as well as increase the capacity of the plant to 300 l/s without additional area. As a result, the upgrading of the

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plant was rely on utilizing the existing units by using simple technologies including tapered contact flocculation (TCF) and plate settlers.

In 1972, contact flocculation has been studied as a process occurred through the filter media by (Ives, 1972). He highlighted the importance of the particle-particle collision efficiency factor and predict that under typical filtration conditions orthokinetic flocculation of particles in filter pores can be significant. After that, (Ives, 1973) mentioned that in case of fixed bed granular filters, flocculation occurs when power dissipates as laminar flow through granular media and he used Kozony-Carmen equation for the calculation of the headloss. In year 1987, (Fadel, 1987) have studied the contact flocculation as a separate process for constructing a new plant by using fixed plastic media with graded sizes and he developed a model to determine the value of the velocity gradient in the contact flocculation for the full range of laminar, transitional and turbulent flow. In year 1991, (Monk and Trussel, 1991) applied the contact flocculation by using a buoyant plastic media that is easily cleaned. In year 1999, (Trussell and Chang, 1999) derived an equation can be used for calculating the headloss through the porous media.

According to the (MWH, 2005), "in this flocculator design energy dissipation is achieved by turbulent flow through a coarse media". (Kawamura, 2000) demonstrates that the coarse media used for flocculation have excellent properties for storing coagulated solids. (Fadel, 1987) reported that the pore size of the media will decreases with time and more head loss will buildup. This condition of filter action will increase the G value to the limit which may cause more flocs damage than flocs formation. Therefore, (Fadel, 1987) suggested the tapered contact flocculation, comprises the use of granular media which consists of three layers of spherical particles with diameter of 5 mm for the top layer, 10 mm for the second layer, and 28 mm for the bottom layer. The reasons for these media were; (a) The large size media is essential for increasing the pore size and reducing the specific surface area of the media in order to reduce the effect of filtration, (b) The configuration of the media layers is important for allowing the growing up of flocs inside the flocculator, in case of the top layer being partially clogged by suspended solids deposition the remaining layers will flocculate the escaping suspended solids, and (c) The high surface loading of 15 m/h is advantageous for reducing the filtration actions and is essential for obtaining the designed G values which were 100, 70, and 40 sec-1 respectively. Also, (Fadel, 1987) reported that the retention time required for the TCF is ranging from 1 to 3 min. On the other hand; the (MWH, 2005) reported that the retention time required for the TCF is ranging from 5 to 10 min.

Inclined plate settlers are strong alternative for upgrading old sedimentation tanks. Inclined plate settlers have overflow rates are much higher than that in the conventional settling basins and are sometimes called high rate settlers. Where, inclined plates or tubes are arranged in parallel, permitting solids to reach surface after short distance. These plates or tubes are oriented in an inclined direction to allow solids sliding from plate or tube surface results in the settled particles depositing in the sludge zone (MWH, 2005). The angle of inclination of the plates should be more than 50° to 60° (Yao, 1970), to allow self cleaning of surfaces occurs. Surface loading rate for plate settlers reaches up to 6.25 m/h which is acting three times the surface loading rate of the conventional settling basins (MWH, 2005). Consequently, the capacity of the existing sedimentation tanks could be increased up to three times the original capacity (Sanks, 1978).

There are certain advantages with the TCF

and the plate settlers, including; simplicity, no moving parts and less required area. The combination of the TCF and plate settlers become a viable option for upgrading such old water treatment plants in Egypt.

This study was conducted in order to evaluate the feasibility of upgrading the old conventional water treatment plant using the TCF and plate settler systems and to examine the performance of these technologies.

2. METHODOLOGIES

2.1 The Situation before Upgrading

The existing plant comprises shore intake, low lift pumps, distribution chamber, plain sedimentation tanks, rapid sand filters, ground storage, high lift pumps, elevated tank and annexed buildings. Table 1 illustrates number and dimensions of the existing treatment units. Figure 1 shows the layout of the existing plant before upgrading.
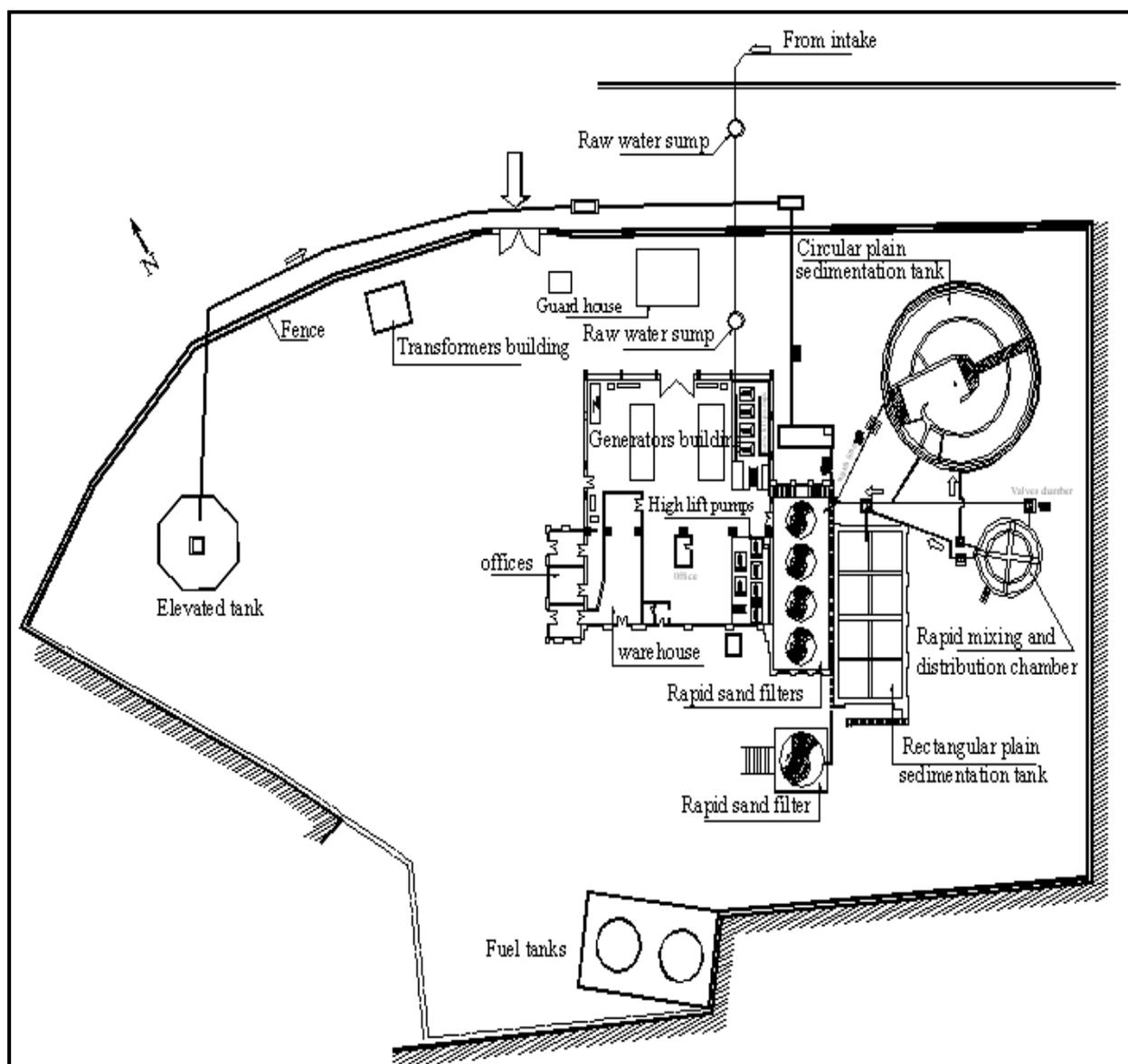
Figure 1   The layout of the plant before upgrading

Table 1   Number and dimensions of the existing water treatment units

The treatment unit	Number of units	Dimensions (m)	Remarks
Circular plain sedimentation tank	1	Φ = 18.00 D = 4.60	Capacity of 60 l/s
Rectangular plain sedimentation tank	2	L = 8.50 W = 4.00 D = 4.80	Capacity of 40 l/s
Rapid sand filter	5	4 (Φ = 4) & 1 (Φ = 6)	Circular tanks
Ground storage	1	400 m^3	Beneath the filters
Elevated tank	1		Not working

The plant had three Plain sedimentation tanks, one of them is circular with a capacity of 60 l/s and the other two are rectangular with a total capacity of 40 l/s. These tanks were not equipped with sludge hopper or any other forms of sludge withdrawal equipment except emptying valves at the bottom of each tank. In the past, the plant was modified by adding alum solution tanks and dosing system which was fed in the distribution chamber where the rapid mixing is achieved by a mechanical stirrer. However, the addition of the alum as a coagulant wasn't effective because the plant doesn't containing slow mixing or flocculation step. Photo 1 and 2 shows the circular and the rectangular plain sedimentation tanks respectively.

The filters house comprise five rapid gravity sand circular filters that made of steel. Filters were in bad condition and most of the mechanical equipments are dilapidated. Therefore, upgrading of the filters house may be not economical and effective.

Ground storage tank was constructed beneath the rapid sand filters with a total capacity of 400 m^3 which wasn't sufficient for both of filters backwash requirements and treated water storage. The storage capacity was about 4.6 % of the total daily production with a short hydraulic retention time of about 1 hour.

Photo 1   The circular sedimentation tank (no.1)

Photo 2   Rectangular sedimentation tanks (no. 2 &3)

2.2   The Solutions Made for Upgrading

The upgrading works were basically focused on increasing the capacity of the plain sedimentation tanks as well as constructing new rapid sand filters. In addition, they also in-

clude the construction of a new ground storage tank and the required modifications of the annexed buildings.

The plain sedimentation tanks have been upgraded by dividing each tank it into two compartments; the first one is assigned for the TCF where a spherical plastic media is employed and the second is assigned for plate settlers. In the TCF compartment, a spherical plastic media is manufactured in the form of modules where the gentle mixing is achieved by the passage of water through the voids space. The fixed bed composed of graded spherical plastic media to obtain a tapered velocity gradient (G) by changing the voids volume. The media used are consisting of two layers contain a spherical plastic media with different diameters and total depth of 2 m. A hydraulic retention time of 3 min and surface loading rate of 30 m^3/ m^2 of media/ hr (0.83 cm.sec^{-1}) were applied. Calculations of the G value has done by the following formula (Fadel, 1987) and the design characteristics for the TCF are listed in Table 2.

$$G = 1.32V \{85.7 (1-E)^2 + (1-E)R\}^{1/2} D^{-1} E^{-2} \quad (1)$$

Where:
V = surface loading rate, cm.sec^{-1},
E = media porosity,
R_e = the Reynolds number, and
D = media particle diameter, cm.

$$R_e = \rho. \ V. \ D \ / \ \mu \quad (2)$$

Where:
ρ = water density 1000 kg. m^{-3}
V = surface loading rate, m.sec^{-1},
D = media particle diameter, m.,
μ = dynamic viscosity, (1.002$\times$10^{-3} kg.s^{-1}. m^{-1} at 20 °C)

Table 2   Design characteristics for the tapered contact flocculation.

Design parameter(s)	Unit	Upper layer	Lower layer
Particle size	mm	20	30
Reynolds number (R)	---	167	250
Media porosity (E)	%	30	40
G value	Sec^{-1}	72	30

After a period of operation time (up to 30 days) the head loss development occurs due to the reduction of the voids space. Accordingly, the contact flocculator requires frequent backwashing. A washing system using water jet was installed to provide sufficient media cleaning.

In the second compartment, poly vinyl chloride (PVC) plates of 6 mm thickness are placed. The plates were fixed at 100 mm space from each other and at an angle of 60 ° to the horizontal. An outlet channel was fixed at the top of the tank to collect the clarified water uniformly by arranging V-notch weirs on both sides of the channel. Sludge hoppers were constructed at the tank bottom as well as drainage pipes were fitted to withdraw the accumulated sludge. A hydraulic retention time of 0.8 hr. and surface loading rate of 129 m^3. m^2. d^{-1} were applied. The area of plate settlers was calculated by using the following formula: (Fadel, 1990)

$$L_r = \frac{L}{e} \quad (3)$$

$$L_u = L_r - 0.013 \ R_e \quad (4)$$

$$SLR_s = \frac{K \ SLR_0}{\sin\theta + L_u \cos\theta} \quad (5)$$

Where:
L_r = relative depth (r),
L = length of plates or tubes (m),
e = perpendicular distance between plates or diameter of tube (m),

L_u = effective relative depth,

R_e = the Reynolds number,

SLR_s = critical surface loading rate or settling velocity ($m^3 . m^{-2} . d^{-1}$),

SLR_0 = surface loading rate for area of high rate settling ($m^3 . m^{-2} . d^{-1}$), and

θ = angle of inclination of settler

All of the existing sedimentation tanks have been upgraded by this procedure. The capacity of the circular sedimentation tank have been increased to 180 l/s instead of 60 l/s, while the capacity of the rectangular sedimentation tanks increased to 120 l/s instead of 40 l/s. Photo 3 and 4 shows the rectangular and the circular sedimentation tanks after upgrading respectively. Figure 2 illustrates the circular sedimentation tank after upgrading.

The existing rapid sand filters have been replaced by a new four rapid sand filters with a dimensions of 7.40 × 9.00 m for each filter with filtration rate of 130 $m^3 . m^{-2} . d^{-1}$. A ground storage tank with a capacity of 3000 m^3 was constructed beneath the new filters for backwash requirements and treated water storage.

Also, the annexed units include; intake, low lift pumps, high lift pumps, alum solution tanks and the chlorination system were upgraded in order to comply the expanded capacity of the plant.

Photo 3 The upgraded circular sedimentation tank.

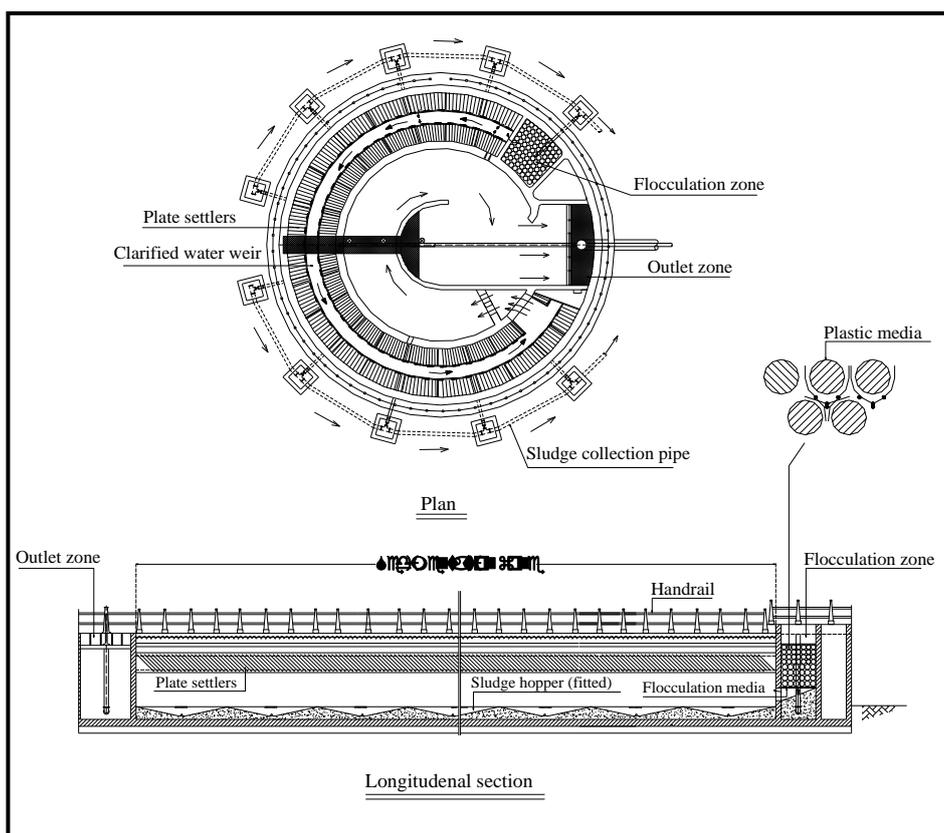**Photo 4** The upgraded rectangular sedimentation tank.

Figure 2   Plan and longitudinal section of the upgraded flocculation and sedimentation

2.2 Analytical Procedures

Water sampling: Composite samples were daily collected from the raw water, clarified, filtered water without chlorination and the chlorinated water. The following key water quality parameters were monitored for six months: Turbidity (NTU), Temperature (°C), Algae (Count/ml), Alkalinity and pH. Turbidity, temperature and pH were measured in situ by using Hi 83200 Multi parameter Ion specific meter. Algal count and alkalinity were measured in the laboratory.

Raw water characteristics: water quality parameters were measured. The results of these specific analyses are listed in Table 3.

Table 3   Result of raw water analysis

Parameter (s)	Unit	Mean value	References
Turbidity	NTU	28	
Temperature	°C	26	Measured in situ
pH	–	7.4	
Algal count	Count/ml	5000	APHA, 1995
Alkalinity	mg /l	170	

3. Results and Discussion

Determination of the feasibility of upgrading the plant means both of technical and economical sides. Technical evaluation is based on the performance indicators including; Turbidity removal, algae removal and the effluent characteristics such as alkalinity and pH. On the other hand, a comparative study between the upgraded plant and construction of a new

plant is conducted for the same conditions. This comparison is including; land requirements, capital and running costs.

3.1 Technical Performance

3.1.1 Performance of the upgraded sedimentation tank

Alum solution was used as a coagulant with average dose of 30 mg/l and maximum dose of 42 mg/l based on the results of the Jar test. The concentration of the alum solution was 10 %. The turbidity of the clarified water was ranging from 2.0 to 6.0 NTU while the raw water turbidity was ranging from 15 to 35 NTU. The average removal efficiency of turbidity was 90 %. This emphasize that the upgraded tank performance was stable during the period of this study as well as the good performance of the contact flocculation to form good settable flocs.

3.1.2 Performance of the rapid sand filters

The turbidity of the filtered water was ranging from 0.3 to 0.9 NTU and 0.4 NTU on average.

According to the (WHO, 2001) 'With good design and operation, treatment plants should be able to produce a consistent supply of filtered water of less than 0.5 NTU. When the turbidity of filtered water is frequently more than 1.0 NTU, problems that need attention are likely'. The average removal efficiency of turbidity was 85 %. In Egypt, the filter run length is usually ranging from 12 to 24 hrs. In this case, the run length increased up to 30 hrs due to the high efficiency of the upgraded sedimentation tanks.

3.1.3 The overall performance

Turbidity removal: raw water turbidity was 28 NTU on average and at the sedimentation outlet reduced to 2.6 NTU. Finally, the turbidity of the filtered water was reduced to 0.40 NTU. It is clear that the majority of turbidity removal occurred through the upgraded flocculation and sedimentation tank. This is corresponds with (Fuller, 1933) 'In all cases experience showed that for successful filtration the coagulation of the water as enters the filter must be practically completed'. Figure 3 illustrates the turbidity changes through the treatment processes.
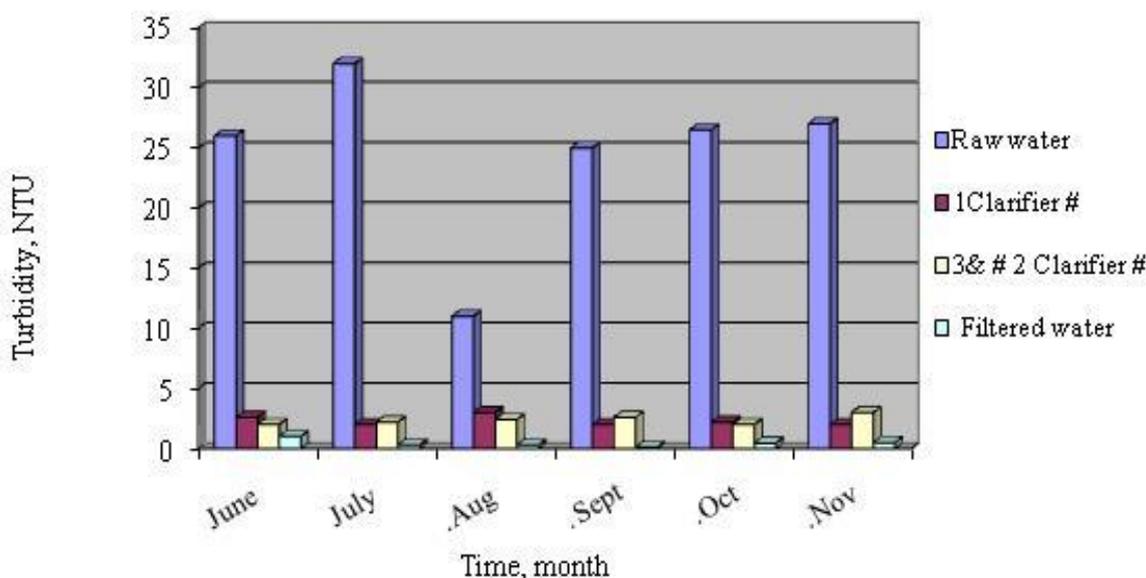

Figure 3   The turbidity changes through the treatment processes.

Algae removal efficiencies were ranging from 94 to 98 %. Algal count in the chlorinated water was ranging from 22 to 44 count/ml. while the influent algal count in the raw water was ranging from 3370 to 6400 count/ml.

pH variations: In general, pH in raw water showed little variation from neutral with a mean value of 7.60 and slightly decreased to a mean value of 7.40 at the sedimentation outlet. The average pH value in the treated water was 7.3 (after chlorination). Mostly, these slight variations were due to the effect of the alum solution as well as effect of the post chlorination through the treatment processes (AWWA, 1999).

3.2 Results of the Economical Comparative Analysis

The results obtained from the operation of the upgraded plant are almost similar to those obtained from the other conventional treatment plants and may be better. Hence, the comparative study was on the basis of the land requirements, running and capital costs. In Egypt, conventional water treatment plants are usually comprises; rapid mixing tank, mechanical flocculator, sedimentation and rapid sand filters.

Great savings are achieved through flocculation and sedimentation processes because of using the existing tanks structure as well as employing no mechanical equipments. Consequently, the energy consumption has been reduced. The comparative study is focusing on these processes regardless of the rapid sand filters which have the same area in both purification modes. Table 4 presents the results of the comparative analysis conducted between the conventional and the upgraded plant.

Results obtained from the comparison, clearly demonstrates that the application of TCF and plate settler system in upgrading water treatment plants is definitely advantageous. This is in addition to savings in costs of land area covered by the flocculators and the settlers.

Table 4   Results of the comparative analysis.

Parameter (s)	Unit	Upgraded plant	Conventional Plant	Remarks
Area required	ha.	0.75	2.00	–
Construction cost	L.E	9,000,000	70,000,000	The cost of the land is not included
Running cost	L.E/m^3	0.35	0.55	–
Construction period	month	12	24	–

CONCLUSIONS

The following conclusions can be drawn based on the field investigations of conventional and upgraded plants using TCF and plate settler system:

a. The TCF have a high potential in upgrading existing flocculation and sedimentation tanks.
b. The main advantage of inclined plate settlers lies in their capability of coping with plant overloading conditions. Such settlers could be easily installed in existing sedimentation tanks as a solution to increase their capacities at minimal cost compared to other solutions such as constructing new tanks. Installation or removal of inclined plates would not interfere with normal

operation of existing sedimentation. tanks.

c. In comparison with the conventional flocculators and settlers, the TCF and plate settlers are simple, efficient and low cost technologies which are suited for upgrading of old plants.

d. Improved efficiency of the sedimentation tank generates less filter backwashing equates to significant operating cost savings for both water and electricity.

REFERENCES

APHA, AWWA, WEF (1995). *Standard Methods for the Examination of Water and Wastewater 19th ed.,* USA.

AWWA (1999). *Water Quality and Treatment 5th ed., a handbook of community water supplies*. AWWA and McGraw-Hill, Hardback, USA.

Fadel, A. A. and Baumann, E. R. (1990). Tube Settler Modeling. *J*. Environmental Engineering, *American Society of Civil Engineers*, 116 (1): 107-124

Fadel, A. (1987). *Taper Contact Flocculation*. Proceeding of the 39th Annual Convention of the Western Canada Water and Wastewater Association. Saskatoon, Saskatchewan, Canada.

Fuller, G. W. (1933). Progress in Water Purification. *J. AWWA*, 25 (11): 1566-1576

Ives, K. J. and Bhole, A. C. (1973). Theory of Flocculation for Continuous Flow Systems. *J. Environmental Engineering Division, ASCE*.

Ives, K. J. (1972). *Optimization of Deep Bed Filtration*. First Pacific Chemical Engineering Congress: Part 1: Session 2, Separation Techniques, Society of Chemical Engineers, Oct. 10-14, Japan.

Kawamura S. (2000). *Integrated Design and Operation of Water treatment Facilities 2nd ed.,* Wiley-Intersience, New York, USA.

Monk, R. and Trussell, R. (1991). Design of Mixers in Water Treatment Plants: Rapid Mixing and Flocculation, In *Mixing in Coagulation and Flocculation*, A. Amirtharajah, M. Clark, and R Trussell (eds.), American Water Works Association Research Foundation, Denver, USA.

MWH, (2005) Water Treatment, Principles and Design 2nd ed., Wiley, Netherland.

Sanks, R. L. (1978). *Water Treatment Plant Design 3rd ed.,* Ann Arbor Science Publishers Inc., USA.

Trussell, R., Chang, M. (1999). Review of Flow Through Porous Media As Applied to Headloss Through in Water Filters. *J. Environ. Engr.*, 125, 998-1006

WHO, (2001). *Upgrading Water Treatment Plants*. TJ International Ltd, Padstow, Cornwall, UK.

Yao, K. M. (1970). Theoretical Study of High Rate Sedimentation. *J. WPCF*, 42 (2): 46-48.