Potential Use of DAF Process in New WTP in Upper Egypt

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Abstract

Conventional water treatment processes, that were installed and used long ago in Upper Egypt, used to treat raw water with fluctuating suspended solids reaching a peak of 3000 mg/l during flood times before Aswan High Dam construction. The spectacular changes in raw water quality following the construction of the Dam were reflected in silt and coarse particulates deposition and increased number of algae. Dissolved Air Flotation (DAF) process is known to be effective in separating low-density particles contrary to sedimentation. This study addresses an investigation of the changing quality of raw water in the study region, using the fundamental characteristics of DAF to identify its potential use as the main treatment process. The study is conducted through identifying the main characteristics of raw water and predominant types and sizes of organic species to be removed. Application diagrams for particles separation for both DAF and sedimentation were developed relating particle size, density, settling velocity and influent water temperature. The study also addresses the merits and demerits of DAF process that shows the system compatibility with changing raw water in addition to expected high removal efficiency within a smaller footprint in the plants.

1. Introduction

Nile River has ever provided Egypt with water for drinking, irrigation, and replenishment of fertile soils. Following the construction of Aswan High Dam (AHD), an artificial reservoir extending 500 km over an area of 6,000 km^2 was constructed upstream the Dam with mean and maximum water depths of 70m and 100m respectively, thus trapping large amounts of silt. Water treatment plants in cities in Upper Egypt have used conventional water treatment processes consisting of coagulation, sedimentation, and sand filtration for more than seventy years. Influent suspended solids varied seasonally reaching a peak of 3000 mg/l during flood times.

Manuscript received from Dr. Hazem I. Saleh
Accepted on : 18 / 6 / 2002
Engineering Research Journal Vol 25,No 3, 2002 Minufiya University, Faculty Of Engineering , Shebien El-Kom , Egypt , ISSN 1110-1180

However, there has been a dramatic change of water quality of the Nile since the construction of AHD in the early 60s. The deposition of silt and coarse particulates upstream the dam was coped with an increasing number of algae in the lake, this effect also extended to some reaches downstream the Dam. It is not uncommon to find treatment plants having almost the same influent and effluent low turbidity, and suffering from problems of algae growth on the sides of the settling tanks (Saleh, 2001). Existing WTP and new plants should consider these changes in their design and operation practices. A number of small and temporary treatment units are also installed at selected areas in the study region to cover shortages of water supply, however, there is a lack of long-term data on performance of such units.

Dissolved Air Flotation (DAF) process has been known to be effective for the separation of low-density particles while sedimentation is highly effective in separating heavy particles. Schofield (2001) presented an extensive review of DAF use in drinking water production including 40 references for DAF application around the world and can be referred to. The review outlines the development of DAF in potable water treatment highlighting benefits, disadvantages, and recent advances in this field. Hargesheimer and Watson (1996) reported successful use of DAF over other conventional processes for removal of nine different algal species from Elbow River in Canada that were causing taste and odor problem.

Olson (1993) reviewed the new applications of DAF in potable water treatment highlighting design and operational experiences in Europe and the United States and reporting the main design criteria of several plants. As an example of the extent of DAF application, 25% of the water treated for potable supply in the Netherlands will be treated by DAF after commissioning of currently executed projects. As more knowledge of theory and fundamental of DAF process is developed, some early design works were judged to be over-designed thus the possibility of further reduction in construction and operational costs of similar facilities. Currently, there is no large scale application for potable water production in Egypt, an this study is carried out to investigate, through the fundamental characteristics of DAF process, its potential use for treating raw water from Lake Nasser in Upper Egypt taking into considerations the main characteristics of raw water quality and other conditions as working temperature, particle size, density, etc.

2. Water Quality at the Study Area

The main changes of concern for water treatment processes following the construction of AHD were linked to suspended solids and algae content. Currently, water released from the reservoir is very low in suspended inorganic particles and its solid content is mainly due to phytoplankton. These changes are the results of physio-chemical and biological transformations occurring in the reservoir, i.e. sedimentation, evaporation, and primary production.

- *Physico-Chemical Characteristics*

Monitoring of physico-chemical parameters for River Nile water was usually concerned with raw water quality downstream AHD where the impact of residential community may start to show, as the work reported by Beacher et al. (2000) reporting values of suspended solids (SS) ranging from 6 to 18 mg/l, COD and BOD_5 values ranged from 1-22 mg/l and 0.8-4.0 mg/l respectively. Figure 1 shows the seasonal variations in water turbidity at AHD site before and after construction indicating the disappearance of the high seasonal peak of suspended solids incorporated with flood events, also denoting the decrease in SS with time. The World Lakes Database (html) reported a long-term monitoring of Lake Nasser water quality as summarized in Table 1 from which it is clear that the lake exerts a long-term sedimentation action on heavy suspended particles resulting in less SS at extended depths.

Water temperature affects the process of particles separation, as water temperature may change widely in the reservoir, depending also on WTP inlet location. Reported surface water temperature is considered as a maximum operating value in any constructed WTP while lower values, slightly over freezing, may still be encountered though rarely, thus a low temperature of 5 °C was also considered in the current study.

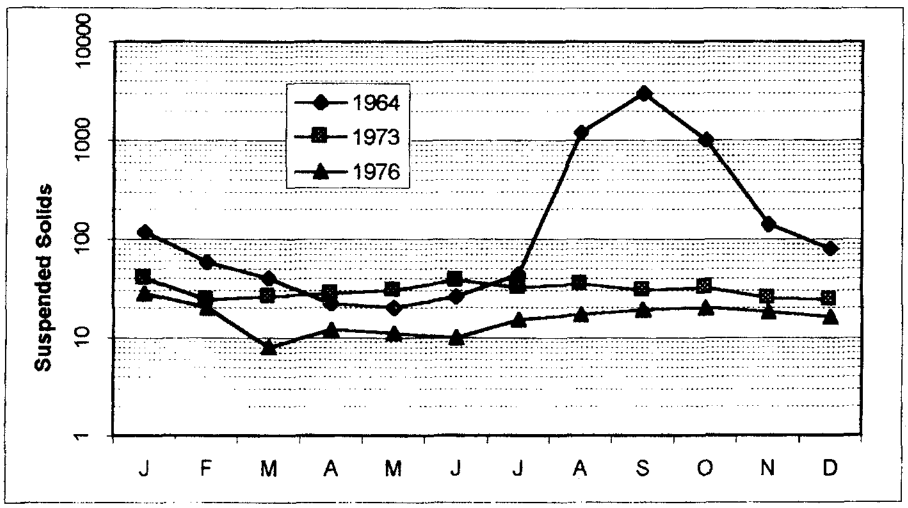

Fig. 1 Suspended solids at AHD site before and after construction

Table 1 Selected water quality parameters at AHD

Parameter	unit	reported range
Suspended Solids		
@surface:Jun-76	mg/l	42
@surface:Mar-84	mg/l	20
@ 1m depth: Mar-84	mg/l	36
@ 22m depth: Jul-85	mg/l	36
@ 28m depth: Sep-86	mg/l	7
Air temperature	°C	25 - 40
Surface water temp.	°C	15 - 30
pH	units	7.9 - 8.2
COD	mgO_2/l	6 - 13
Phosphorus	mg/l	0.05 - 0.75
TDS	mg/l	140 - 200
EC	microS/cm	230 - 330

- *Biological Features*

The formation of Lake Nasser was accompanied by alterations in the environmental conditions that consequently affected the biota. Such alterations led to corresponding changes in the diversity, density and distribution of the phytoplankton community. Table 2 shows the concentration and composition of different microbial species found at AHD site. Based on these findings, the authors conducted a desktop work to identify the probable sizes encountered in nature for these species as shown in Table 3. As the phytoplankton biomass is most abundant, it is the main concern for removal in this investigation. Diatoms and cyanobacteria were reported to be dominant species (Shafik, 2000, El-Otify, 2000). Lake Nasser also includes several floating macrophytes (*Eichhornia crassipes*) that are free-floating aquatic plants ranging from few millimeters to centimeters in diameter or size and can be removed by fine screening.

Table 2 Biomass of phytoplankton and zooplankton at AHD

Biological Species	**% of Total**	**Biomass Concentration**
Phytoplankton		$3 – 7 \times 10^6$ / liter (higher value in summer)
Cyanophyta	75 – 85%	
Bacillariophyta	20 – 10%	
Others	5%	
Zooplankton		$15 – 35 \times 10^3 / m^3$
Copecoda	80%	
Cladocera	18%	
Rotifera	2%	

Table 3 Normal sizes of microbiological species found at AHD

Biological Species	Size Range (micrometer)	Reference
Phytoplankton		
Cyanophyceae *Microcystis aeruginosa, Anabaena flos-aquae* *A. flos-aquae f. spiroides, A. cunningtonii* *Anabaenopsis tanganikae, Lyngbya limnetica*	4 – 50	Kawagida (1993)
Bacillariaceae, Diatoms *Melosira granulata, M. varians, Synedra acus*	5 – 300	Kawagida (1993)
Chlorophyceae *Volvox globator, Eudorina sp. Pediastrum sp.*	2.5 – 800	Kawagida (1993)
Zooplankton		
Daphnia *Ceriodaphnia cornuta, C. dubia,* *Diaphanosoma excisum*	250-3000	AWWA (1995)
Cladocera *D. barbata, Bosmina longirostris*	250 – 3000	AWWA (1995)
Copepoda *Chydorus sphaericus, Cyclops sp.*	250 – 1000	AWWA (1995)
Rotifers *Brachionus sp, Keratella sp.*	100-600	AWWA (1995)

After investigating raw water quality at AHD site and the major changes occurring after the Dam construction, which may still be prevailing at downstream reaches in Upper Egypt, a study of the use of the proposed DAF process will herein follow to illustrate its potential application coping with the new characteristics of raw water quality.

3. Potential Use of DAF Process

- *Current Uses of DAF for Water Treatment*

A significant number of water treatment plants worldwide obtain raw water from lakes and reservoirs. In general, these sources contain low-density suspended solids such as algae or organic compounds. The regular conventional flocculation and sedimentation process may not be very effective because the flocs are light and settle slowly unless a very low surface loading rate is specified and costly polymers are fed to the process. Dissolved air flotation (DAF) is an effective alternative as it uses minute air bubbles to float light flocs that are further skimmed off, leaving clear water near the bottom of the tank. Table 4 shows a summary of DAF design and operational parameters used in various treatment plants.

Kempeneers et al. (2001) reported 80% removal efficiency of *Melosira* (<250μm – as reported for lake Nasser) and an overall algae removal efficiency of 74%, over a decade of large-scale treatment plant operation, which guaranteed stable capacity of a dual layer filter downstream the DAF. Crossley et al. (2001) also described the approach to design a water treatment plant of $1.5x10^6$ m^3/day using DAF process getting advantage from previous experiences drawn from operating similar units for water treatment. Olson (1993) reported that comparative studies of construction costs showed that total capital for two treatment plants of 50,000 and 100,000m^3/day capacities using DAF were less by 25% and 8% respectively to analogous plants using high rate sedimentation process.

Table 4 Summary of DAF design and operational parameters

Parameter	Recent studies	Netherlands	United Kingdom	United States
Flocculation				
Time (min)	5 - 8	8 - 16	20 - 29	1.3 - 30
Flotation				
Time (min)	5 - 15	--	5 - 20	5.6 - 12
SOR (m/h)	5 - 15	10 - 20	5 - 12	6 - 10
% Recycle	< 8	6.5 - 15	6 - 10	8 - 40
Sat. Press. (kPa)	345 - 585	400 - 800	310 - 834	480 - 620
Sludge Removal				
Method	mech. scrapers	--	mech. scrapers	mech. scrapers
Frequency 1/h	continuous	--	0 - 2	continuous
Sludge % Solids	1 - 3	0.1 - 8	0.3 - 3	< 1

Source: (Olson, 1993)

- *Theoretical Aspects*

The phenomenon of particles settling can be viewed considering Stoke's law at low Reynolds numbers:

$$V = \frac{g(\rho_1 - \rho)D^2}{18\mu}$$

where: V is the particle settling velocity, g the gravity constant, ρ_l the mass density of particles, ρ the density of water, D is the diameter of particle (spherical shape), and μ is the viscosity of water. In most aquatic plants water content ranges from 80-90%, the remainder represented in protein, fat, ash, and cellulose. The density of these species is thus small and approaches that of water whenever the water content is higher. On the contrary, silts and clay particles sizes have a high specific gravity and will thus behave differently than organic matter in a settling process. Figure 2 shows a relationship developed for the settling velocity of different particle sizes predicted for inorganic particles causing turbidity, e.g. clay and silt with specific gravity (Gs) of 2.65, algae particles with specific gravity 1.05 (Montgomery, 1985), using Stoke's law under the effect of varying operating temperature from 5 °C to 30 °C. The figure clearly denotes an extremely low settling velocity of algae compared with other inorganic particles.

different particles function of their size, density taking into consideration the operating temperature prevailing at the study area that directly impairs water viscosity.

- *Applicability and Technical Merits*

The main concern in water treatment processes is the removal of particulate matters that may shelter pathogens thus promoting successful disinfection in the produced water. Sedimentation is most commonly used for solids separation. Operating surface loading rates (SLR) for most settling tanks may vary from 1-2 m/hr (Kawamura, 2000; McGhee 1991); some facilities in winter may work at lower operating values with lower demand. When particles settle at velocities higher than SLR, satisfactory removal of SS can be expected. Figure 4 shows a graph developed to identify areas where both sedimentation and flotation of SS can work properly. The graph is developed taking into consideration arbitrary boundaries, e.g. SLR = 0.5 m/hr @ water temperature of 5 °C and SLR = 2.0 m/hr @ water temperature of 30 °C, these can be slightly modified based on the exact design values of the competing settling process. As the current study revealed that the abundant phytoplankton of concern for removal would normally have a maximum particle size of 800µm, the diagram was developed for a maximum size of 1000µm.

Areas on the graph corresponding to larger particles size and higher settling velocities are considered appropriate for the application of the sedimentation process. On the contrary, the flotation area, i.e. confined lower than minimum settling velocity boundary, covers both large light particles and small heavy particles, their settling velocities would still not achieve good settling. The use of coagulants such as alum widely used in Egypt and worldwide, will result in aluminum hydroxide floc formation with density around 1.01 g/cm^3 (Montgomery, 1985), besides agglomeration of particles and increase in overall agglomerate size. When silt and clay particles, with higher densities, adhere to the alum floc, both increase in size and total density occur thus favoring the application of sedimentation process. However, when alum is added to flocculate the algae, the overall density remains approximately unchanged. The resulting agglomerate particle size and density would still be allocated in the flotation zone or at most in the intermediate zone shown in Figure 4 thus favoring the concept of DAF process application. The escape of such light flocs in the sedimentation process represents an additional load on the following filters. The surface overflow rate (SOR) for DAF process shown in Table 4 denotes that lower surface area is required for this process compared with sedimentation tanks, offering another advantage when the available area of treatment plant is of concern.

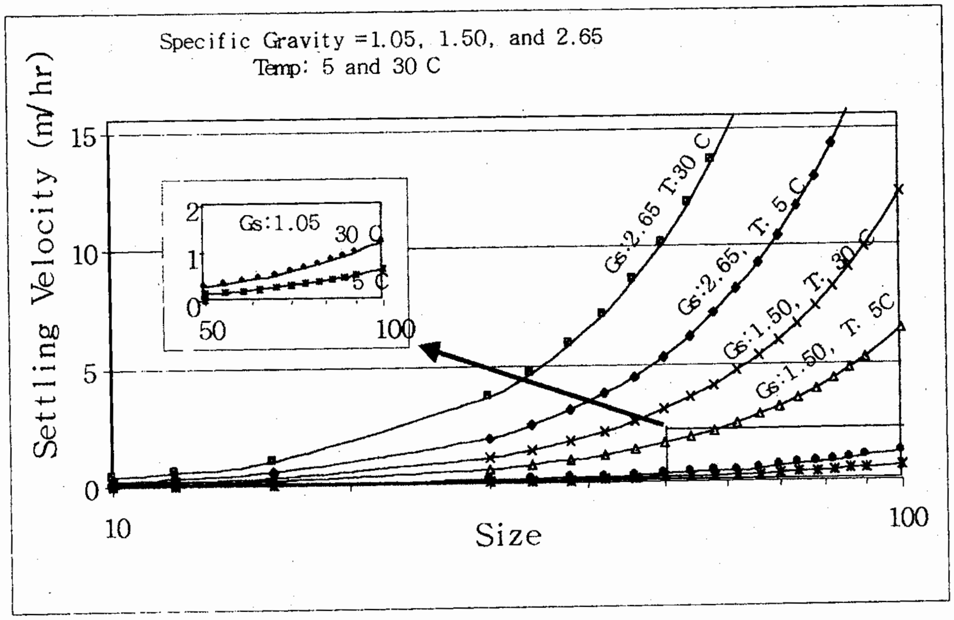

Fig. 2 Variations of settling velocity vs. particle size relative to temperature

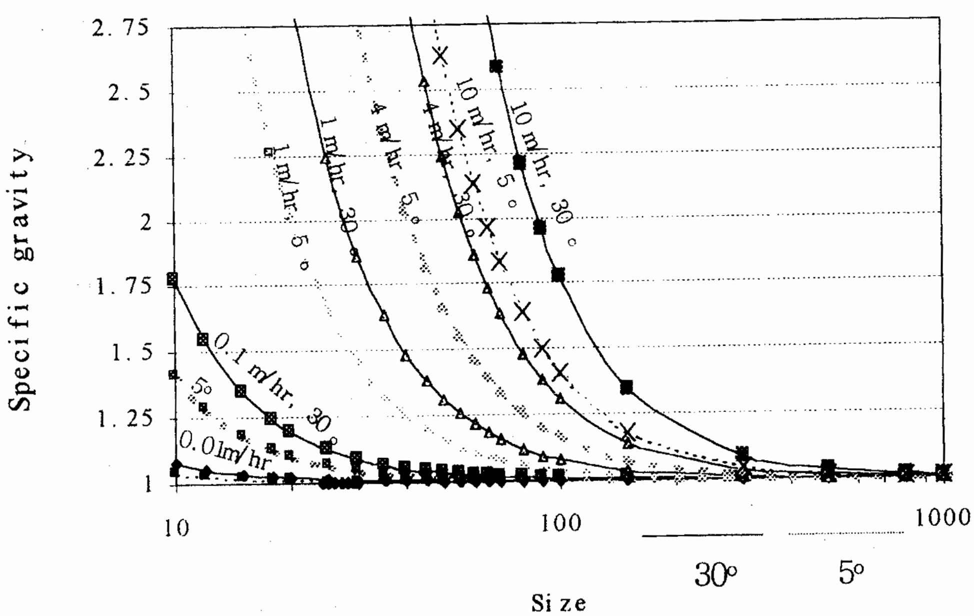

Fig. 3 Predicted settling velocity function of particle size and particle density

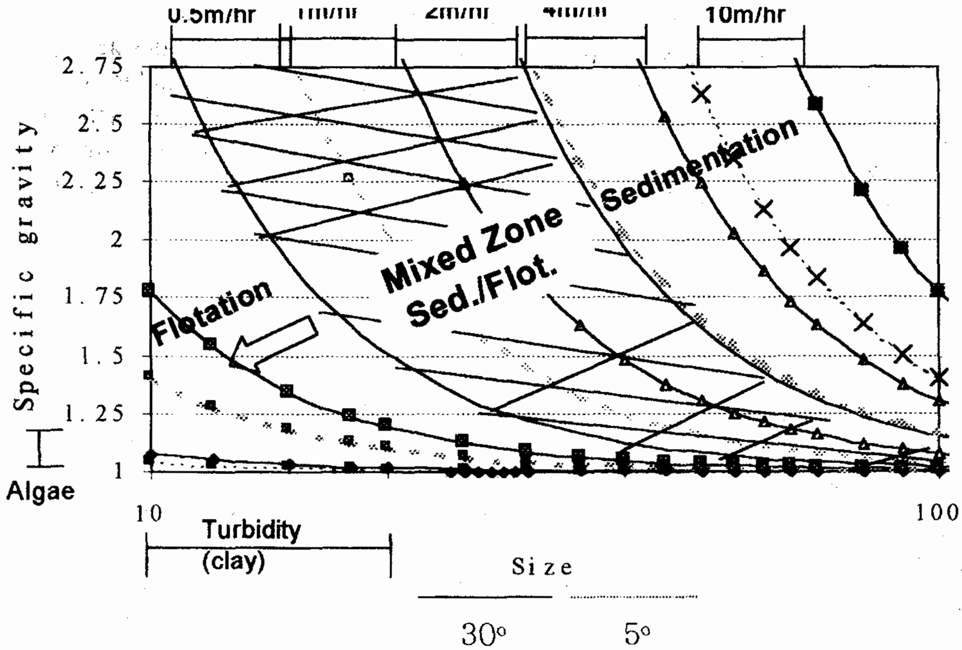

Fig. 4 Illustrative zones for application of sedimentation and flotation processes

In addition, less coagulants doses are required and lower flocculation time is also practiced in order to keep the floc size small enough for proper flotation by the introduced air bubbles. More solids concentration is achieved, and less chemicals are encountered in the removed sludge, thus minimizing sludge disposal problems from the DAF. On the contrary, sweep coagulation may be needed for the sedimentation process in order to entrap the light particles and the low content of inorganic particles resulting in the reverse impact on sludge production.

- *Limitations*

With the absence of large-scale applications of DAF process for potable water production in Egypt, pilot studies are required to confirm operating parameters as related to temperature effect, maximum expected removal efficiency, alum dose, etc. In addition, the application of DAF process requires experienced and trained operators aware of the basics of the process for selection of proper alum dose, flocculation time, and sludge removal in order to achieve the optimum performance of the process.

The theoretical interpretation of particles settling process using Stoke's law is adopted for simplicity. Several other models were developed for describing particle settling especially under the influence of other settling particles. Han and Lawler (1991) reported several models used to describe particles settling velocities, which have their differences and discrepancies, thus the use of Stoke's law to estimate particles settling and removal is regarded as an accepted approach for the development of the current study.

4. Conclusions

Changes in raw water characteristics at Lake Nasser in Egypt was investigated for its physico-chemical and biological quality through identifying variations in suspended solids concentration and the prevailing microbiological species in order to assess the use of DAF process for potable water production. Peaks of high-suspended solids no longer occur after AHD construction, phytoplankton dominates with biomass of $3\text{-}7 \times 10^6$/liter at particle size spectrum of 4 to 800 μm. Settling velocity of algae is considerably low compared with silt or clay. A diagram was developed to predict settling velocities of particles function of their size and density, relative to influent water temperature to the solids separation process. Zoning for preliminary selection of sedimentation and flotation processes was developed; from which it is concluded that the addition of alum for algae flocculation will result in larger flocs with lighter density still favoring their separation through DAF process.

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مقومات استخدام نظام الطفو في محطات تنقية مياه الشرب الجديدة بجنوب مصر

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ملخص البحث

تستخدم محطات تنقية مياه الشرب في مصر النظم التقليدية المعتمدة على الترسيب باستخدام المروبات والترشيح. وقد كانت محطات التنقية في جنوب مصر تستقبل مياه يصل تركيز المواد الصلبة بها إلى ٣٠٠٠ مجم/لتر أثناء الفيضان قبل إنشاء السد العالي. وقد حدث تغير كبير وملحوظ في نوعية المياه في هذه المنطقة بعد إنشاء السد متمثلة في تدني تركيزات المواد العالقة نتيجة لعملية الإطماء خلف السد مع زيادة في عدد الطحالب والكائنات الميكروسكوبية بالمياه. وتستخدم عمليات الطفو بكفاءة لإزالة المواد ذات الكثافة الخفيفة بعكس عملية الترسيب. ويدرس هذا البحث نوعية المياه الخام بمنطقة السد والتغييرات الحادثة بها، وكذلك تصنيف أنواع الكائنات الدقيقة بالمياه لمعرفة حجم ونوعية المواد المطلوب إزالتها في محطات تنقية مياه الشرب. ولقد تم استنتاج منحنيات تطبيقية لفصل المواد العالقة يمكن تطبيقها سواء لعملية الطفو أو عملية الترسيب بدلالة حجم الحبيبة (القطر)، كثافتها، سرعة الترسيب الخاصة بها ودرجة حرارة المياه الخام لبيان مقومات استخدام أي من النظامين في عملية تنقية المياه. وتعرض البحث لمميزات وعيوب استخدام عملية الطفو والذي أظهر موائمة لنوعية المياه المطلوب تنقيتها مع توقع كفاءة عالية في إزالة هذه المواد بالإضافة إلى شغل مساحات أصغر دخل محطات تنقية المياه.