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Experimental Investigation of An Industrial Wastewater Treatment Unit Using Multi Filter Hybrid with Parabolic Trough Solar Concentrator

M. Hamdy El-Awady [1*] and Hamdy El-Ghetany [2]

[1] Water Pollution Research Department, National Research Centre, P.O. Box 12622, El-Buhoth St., Dokki, Cairo, Egypt; hawady@yahoo.com Orcid.org/0000-0003-1014-7260

[2] Solar Energy Department, National Research Centre, Dokki,12622, Giza, Egypt; hamdy.elghetany@gmail.com

Abstract

Due to the shortage of fresh water in residential, agricultural and industrial sectors, wastewater treatment (WWT) should be applied for reuse purposes. This study focused on innovative hybrid system for the industrial WWT and recycling using parabolic trough-solar collector (PTC) to treat WW by photo-catalytic oxidation enhanced direct sun light. The system consists of two pillars; first is six consequent filter units. They filled with; gravel; course sand; fine sand; natural coal; activated carbon; and zeolite. Filters were connected in-series and in-parallel. Filters were designed to remove solids, soluble pollutants and heavy metals. PTC is acting as photo-catalytic degradation of the persistent pollutants. It consists of a metallic parabolic steel structure with reflective surface and receiving tube. PTC lets water to be exposed to the solar radiation to destruct the residual contaminants in the final outlet. To optimize system efficiency and to maximize water exposure to solar radiation, a 50% nano TiO_2 emulsion was coated as photo-catalytic degradation enhanced with sun light. Solar exposure time was increased by coating 20 glass circular baffles to lengthen the water path. The system achieved noticeable efficiency of the treatment stages either for physically and chemically steps in the range of solar radiation dose.

Keywords: Industrial wastewater; treatment; solar-energy; evaluation; recycling; safe disposal

1. Introduction

In view to the present rapid shortage in water resources of Egypt, and to the great demand of water especially in the newly constructed industrial areas, it is essential to upgrade the overall water resources management plan that includes the magnification and recycling the industrial treated effluent. Water demands for agricultural, industrial and residential sectors were increased rapidly in the last few decades and will be increased in the future due to the need to compensate the required water demand. One of the strategic solutions is to remediate and reuse the treated industrial and agricultural WW. Quite a large amount of water could be saved by recycling treated industrial wastewater by applying photosensitization process. Photocatalysis (PC) is a clean process for enhancing reactions that are assisted by natural renewable energy light. Consequently, titanium dioxide (TiO_2) is considered one of the popular developed photocatalytic materials, where it is widely used because it has a remarkable catalytic activity, stability and very high affordability. Egypt is pleased specifically with abundant solar radiation with an average of 5.5 kWh/.m^2.per day. Sequential treatment of multi-filters followed by PTC produces an effluent quality complying with reuse purposes, taking into consideration disinfection as essential to minimize health risks associated with effluent reuse. Consequently, the current article is focusing on industrial wastewater (IWW) post-treatment using photo-catalytic degradation enhanced with sun light. One of the common wastewater treatments categorized as physical/chemical method that comprises of precipitation, coagulation, carbon filtering followed by disinfection to get red any residual microbial load. As a combination of physical/ chemical process. In order to reduce the negative environmental impacts of waste cement bi-pass and to be reused as a treatment material, waste reclamation especially for highly polluted WWT. It was also paid a great attention as a no cost treatment material as reported by El-Awady [1], and El-Awady& Ali [2]. An integrated treatment system in

*Corresponding author e-mail: drhamdyelawady@gmail.com .; (M. Hamdy El-Awady).
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combination with potential solar dryer for industrial wastewater has fulfilled the phenomenon of zero-liquid discharge (ZLD). It became urgently needed to lower water shortage and protecting the water resources from pollution which has been carried out [3].

The treatment system is proposed as an attracting option for the treatment of polluted ground water, as well as WW. Homogeneous catalysis that utilizes Photo-Fenton technique and Heterogeneous catalysis includes TiO_2 and H_2O_2. As the solar radiation is the most plentiful and widespread light that presents the most important energy source on earth, it is obvious that solar radiation light can positively induce chemical reactions. Organic pollutants discharged from industrial wastes are still considered the main source pollution, where solar light can greatly contribute to the partial decomposition to the complete demolition of those environmental hazardous pollutants. In addition, advanced oxidation process (AOP) advanced photo-catalysis that uses the high oxidant and non-selective hydroxyl radicals to react with almost of all classes of organic compounds which lead to their total mineralization or to form biodegradable intermediates.

This approach become more attractive when sunlight is implemented as solar energy source and is generally identified as solar photo-catalysis (SPC). Most of SPC treatments are semiconductor photo-catalysis using TiO_2 which is considered the most popular usable semiconductor and photo-Fenton. It created the highly oxidant hydroxyl radicals that help to encourage the degradation of hard degradable contaminants. Solar photochemistry through AOP is an elegant application of fundamental photochemistry using sunlight as energy source has a great advantage to reduce costs. Fujishima et al. [4]; Pirkanniemi & Sillanpaa [5] showed that AOP enabled the use of sunlight as energy source: heterogeneous photo-catalysis on using semiconductors while, homogeneous photo-catalysis on using photo-Fenton processes.

Moreover, Malato et al. [6] showed that the solar emission spectra on starting at ƛ 300 nm can be compared with the absorption spectra of TiO_2 and of Fenton reactant. Heterogeneous photo-catalysis activated by sunlight uses near ultraviolet solar radiation spectrum at ƛ380 nm and homogeneous photo-catalysis by photo-Fenton uses a larger portion of solar radiation spectrum with ƛ up to 580 nm. These processes are proficient in the photo-degradation of persistent organic pollutants. They are considered innovative ways of using a renewable energy and very promising technologies in regards with environmental remediation. PC is a combination of photochemistry/catalysis process, where direct light and catalysis are simultaneously used to accelerate the chemical reaction. Heterogeneous PC is a sunlight activated process that oxidizes species to mineralize organic pollutants via TiO_2 as a catalyst. TiO_2 /PC was also followed the green chemistry key principles as stated by Anastas& Warner [7]; Hermann et al [8]. The common radiation with wavelengths higher than 600 nm didn't have any utility for photo-catalysis processes as reported by Bahnemamm [9] and Malato et al [6].

Water desalination, plantation and wastewater treatment system was constructed and field tested carried out under actual meteorological conditions using an integrated solar green house (ISGH). It was fulfilling wastewater treatment for safe disposal as concluded by El-Awady et al [10]. In addition, and at 2015, the performance of a novel solar IWWT unit for reuse was evaluated as a non-conventional treatment and decontamination of highly polluted WW [11]. Such solar degradation was a new approach and intense focus of investigations revolutionary technological applications in the 21st Century. Textile IWW contributed high organic load, toxicity and carcinogenicity. In addition, an integrated solar power system was designed and setup with a complete treatability study for water treatment plant and greenhouses irrigation system. The system was fed with treated mixed surface/ drainage water in North Delta, Egypt using suitable greenhouse irrigation as studied by Okasha et al [12].

The parabolic trough concentrating collectors consisted of a reflecting surface, receiving tube, and metallic structure. The solar radiation falling on the PTC is reflected on the receiving tube located at the line focus of the parabolic trough. Solar driven AOPs showed an excellent environmental remediation method to destroy persistent organic pollutants that hardly treated by biological processes. Therefore, Andreozzi et al [13]; Chong et al [14]; Comninellis et al [15]; Matilainen& Sillanpaa [16] recorded that methodologies such as AOPs allowed the maintenance of POPs quality were essential. Typical examples of end-of pipe from industries containing dyes were efficiently mineralized by photo-catalysis as concluded by Guillard et al., [17].

Moreover, the photocatalytic reaction of accelerating degradation reactions that assisted by solar irradiation in presence of TiO_2 is considered one of the most widely developed photocatalytic components. It was due to its high catalytic activity, stability and very affordable (Muhamed D et al [18]. Moreover, El-Awady M.H. et al [19] evaluated the reduction of sulfate ions from the IWW using advanced calcium-aluminum precipitation method (ACAPM), and declared the factors affecting the reduction of sulfate ions at their optimal experimental conditions.

2. Description of the hybrid chemical-solar system

The presented solar IWWT system consists of the following components as shown in Fig 1:

2.1. Wastewater elevated storage tank
2.2. Pretreatment filters group (Six units)
2.3. Connecting plumping tubes, measuring and control devices.
2.4. Solar Reactor (PTC)

Fig 1. Layout of the hybrid filter-solar IWWT system

2.1. The wastewater elevated storage tank:

A wastewater plastic storage tank is purchased, prepared with the inlet and outlet openings with flow control devices as installed in the Fig1. Then the tank was mounted on the top of the building with 4.0 m height to provide potential head to that create the pressure drop of the system.

2.2. Pre-treatment filters group and analyses

The pre-treatment filters group consisted of six filters as shown in Fig 2. Each filter has a cylindrical shape PVC pipe with 4" diameter and 1 m length. The sandy combined gravel filters removed and trapped small bugs or organisms, algae, suspended solids and any other large particles in the wastewater. The sequence of operation ensured that the filters must be cleaned using "backwashing" before utilization. To remove the particles from the filters, pressurized air or water is forced backwards to confirm filter cleaning and the outlet dirty water is drained to waste. After filter cleaning process, it can be operated normally again.

The filter that contains a granular activated carbon primary works through adsorption to traps some particles in which the organic matter present in water "sticks" to the carbon granules. This filtration process helps to eliminate color, taste, odor, and other organic matter problems. Microorganisms found inside those crevices, feeding on the nutrients in the water and the particles that stick to the carbon. Some design criteria should be considered for selecting the appropriate types of those filters like type of granular activated carbon, the contact time that may range from 10 to 20 minutes. If the contact time is not achieved between organic matter and the carbon granule, the adsorption process is not achieved properly. Some organisms and dissolved matters pass through the first unit like bacteria and calcium. Also cleaning process should be done to the carbon filters by regular backwashing. Knowing that backwashing will not remove any matter that is adsorbed to the carbon. In case of occurring carbon adsorption with all the organic matter, it is said to be "exhausted".

In the present work, toxic heavy metals are removed from water by accumulating it on the surface of natural zeolite. Zeolite filter was filled with crushed media using secondary crusher and finely ground to less than 200 mesh to be used for chemical removal and adsorption applications. Scanning electron microscopy (SEM) was used for studying the morphology of the used zeolite by a field emission scanning. Physico-chemical analyses of each experimental, post treatment experiments as well as operational stages have been detected and carried out at their optimal operating detection limits. Finally, all analyses have been carried out according to the American Standard Methods for water and wastewater, APHA, 23rd Eden, 2017 [20].

2.3. Connecting tubes

The IWWT system was designed to be capable to evaluate each filter or a combination with several filters that connected with or without the solar reactor. Sampling points were installed in such a way to get sample as per the experimental procedure.

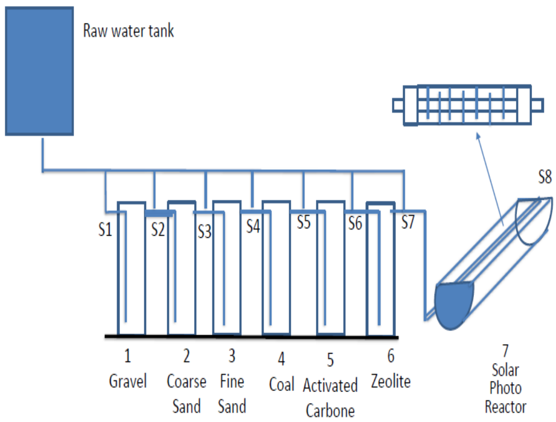

Fig 2 Layout of the pre-treatment six filters group

2.4. Solar Reactor

The proposed solar reactor is designed to be a line focused parabolic solar collector. It consists of four components. The first one is a metallic steel structure that designed by such a way to make the system oriented facing south and has the ability to be manually adjusted for solar tracking. The second part is the parabolic trough reflective surface which consists of two sides; each side has 6 curved glass mirrors with 0.50 m length. The both sides form the reflective surface with total dimensions of 1.0 m aperture width and 3.0 m length. The reflector support structure is made from a metallic frame taking the shape of Parabola. The most important part is the third one that contains the receiving tube. It is designed to work as solar reactor. It consists of a metallic iron steel pipe with 2" diameter to be fixed in both parabolic trough sides. By using two connection groups, a 4" diameter Pyrex glass tube is fixed on the 2" diameter metallic iron steel pipe. The designed system obliged the inlet wastewater to pass only in the annular space between the pipes. By such a way, the water passed on the outer layer of the iron steel pipe and the inner surface of the Pyrex glass tube. This means that the wastewater is directly exposed to the concentrated solar radiation in the parabolic line focus. In order to make the exposure of water sample to solar radiation more effective, a TiO_2 has been used as a photo-catalytic degradation enhanced with sun light. Then the TiO_2 emulsion has been used as a paint to make thin film coated of TiO_2 on the outer surface of the iron steel pipe. In order to increase the retention of the exposure time of the water sample in the solar reactor, 20 circular baffles were designed by such a way to lengthen the water pass. A photographic view of the parabolic trough along with the receiving tube is shown in Fig 3.

Fig 3 Photographic view of the parabolic trough along with the receiving tube

3. Results and Discussion

To evaluate the performance of each unit for industrial wastewater treatment in the integrated system under investigation, two different industrial wastewater samples have been used. The first one was collected from Paper Mill Manufacturing Co., while the second was from Dairy Processing Agricultural Farms. Six sequential filters with different packing materials are the main components of the system; starting by: Gravel Filter followed by Sand Filter, Natural Coal (NC), Activated Carbon (AC) and finally Zeolite (Z) unit. Additional solar PTC is connected at the end of the multi-filter units. All the presented filters are designed to be connected in-series, in-parallel, as well as series/parallel connections, respectively. The filled media in the present work are capable to get-rid of almost all suspended solids, to uptake and remove soluble pollutants as well as heavy metals (HMs) from IWW samples by physical adsorption and chemical absorption of HM on the surface of NC, AC, Z. The following are physio-chemical results showing the performance and efficiencies of the six mentioned treatment units (filters) with regards to raw and treated wastewater as represented in the following figures. The PTC unit is used as a post treatment step to achieve the needed water quality from the integrated system as a whole. Consequently, several runs were carried out to investigate the effectiveness of each single unit representing each physical treatment performance. The optimal flow rate and hydraulic retention time for the integrated treatment system have been calculated from the equation:

$$V = HRT \times Q$$

Where; V = Volume of treatment system (liter), HRT = Hydraulic retention time (second) & Q = Water Flow rate (liter/second). As a sample of the experimental results, Fig 4 shows the values of the chemical oxygen demand (COD) of the raw wastewater and the treated outlet from each filter, consequently, the percentage removal after passing through the sequential filter group. It can be seen that 67% of the contaminants in the raw IWW can be removed along the filters group prior passing through the PTC as shown in Fig 5. Moreover, due to the presence of total suspended solids (TSS), turbidity (NTU) and other effluent contaminants, if the raw IWW was passed directly into the PTC as shown in Fig 6, only 33% of the contaminants were removed.

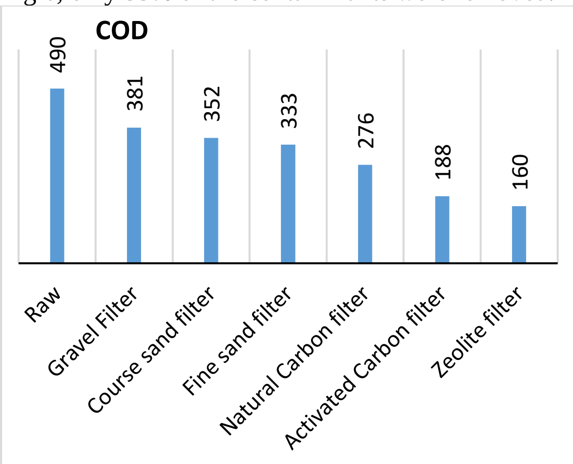

Fig 4 Removal efficiency of COD of the raw IWW after passing each filter

Fig 7 shows that the values of total suspended solids (TSS) of the raw wastewater and the values after passing each filter. While the percentage removal after the raw sample passing through the sequential filter group. It can be seen that 90% of the contaminants can be removed from the filters group prior passing through the parabolic trough solar collector (PTC) as shown in Fig 8. Due to total suspended solids and turbidity and other effluent parameters, when the raw water sample passed directly into the PTC as shown in Fig 6, only 33% of the COD value was decreased and Fig 9 showed that only 25% of TSS value was decreased.

Based on the results shown in Figs. 4-9, it is recommended to pass the wastewater sample to the sequential filter units followed by solar PTC. The previous obtained results gave a guide for the selection and numbers of separate units in parallel or in series to give the optimal sequence of the selected units and their order in the integrated system to give the maximum treatment efficiencies.

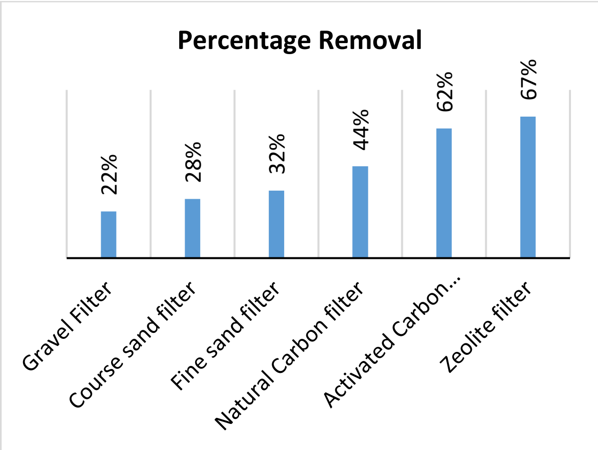

Fig 5 Removal efficiency of raw IWW passing through the sequential filter group

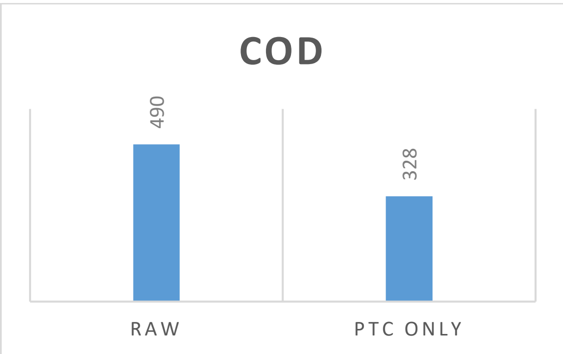

Fig 6 Effect of using only PTC in the solar water treatment

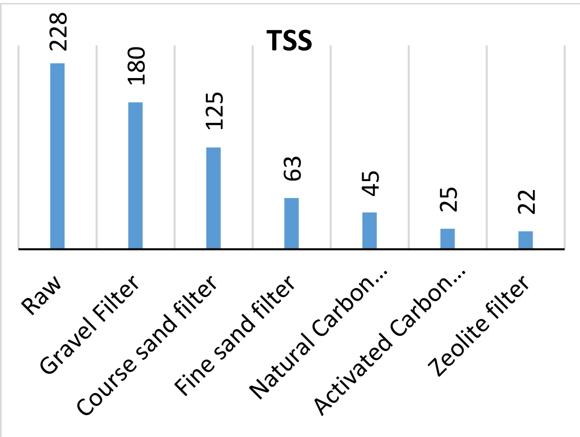

Fig 7 Measured TSS values for IWW and through treated sequential filter group

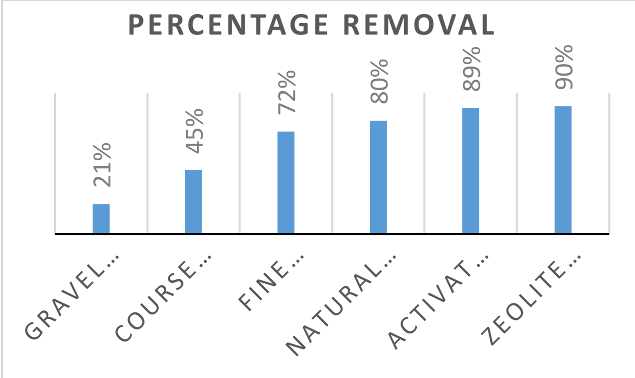

Fig 8 Removal efficiency of TSS from IWW through the sequential filter group

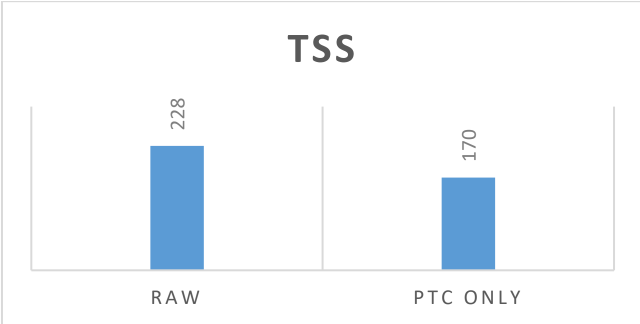

Fig 9 Effect of using only PTC in the solar WW treatment

The obtained results in Figs. 4-9 indicate that:

1- Separate filter/Colum removed part of the TSS content in addition to part of organic matters. It is depending mainly on the nature of packing material.
2- To obtain required water quality or specific percentage of treatment; two or more filter units are needed to be connected in series.
3- Gravels, course sand and fine sand filters are acting as SS removal with variable rates that depending on the particle sizes in the raw wastewater and on the intermediate spaces of the filter medium.
4- Natural coal, activated carbon and zeolite filters functioning as an efficient suspended solids as well as soluble pollutants removal.
5- PTC works efficiently at very low suspended solids content and calculated exposure time to fulfill efficient photo-catalytic degradation.
6- The required treated water quality is directly proportional to the number of selected units and its order in the system.

In order to verify the efficiency of the proposed system; raw IWW samples have been collected along one month from Dairy production Farm, located at an Industrial Zone, North Cairo, Egypt. The obtained results of raw and treated samples have been calculated from three successive runs. The obtained results from experimental work indicated that the optimal contact reaction time is 30 minutes along the experimental runs for all constructed filters. Figures 10-12 show the variation of total chemical oxygen demand (COD_{tot})/ soluble chemical oxygen demand (COD_{sol}), total suspended solids (TSS) for all filter's unit, respectively followed by PTC as well. All analyses have been carried out according to "The American Standard Methods for Water & Wastewater Analysis, APHA, 23rd Eden, 2017" [20].

The obtained results indicated that the optimal contact reaction time is 30 minutes along the experimental runs for all constructed filters. The operating parameters should be checked for each type of waste, because each has its specific characteristics. The operating parameters should justify upon each type of actual waste.

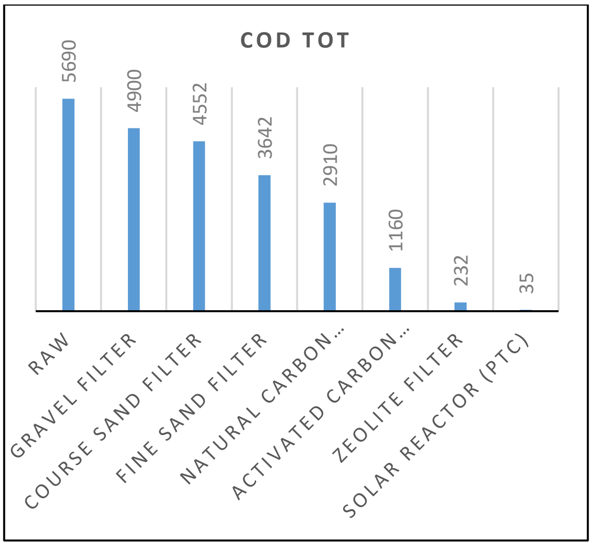

Fig 10 a Variation of COD-tot throughout the experiment

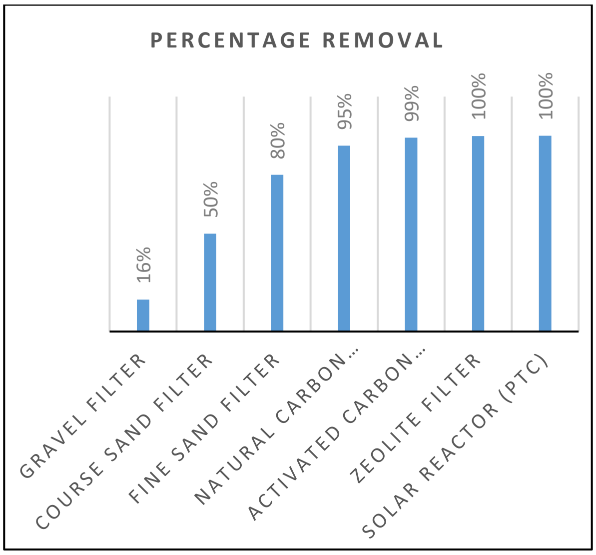

Fig 10 b % Removal of COD-tot, variation throughout the experiment

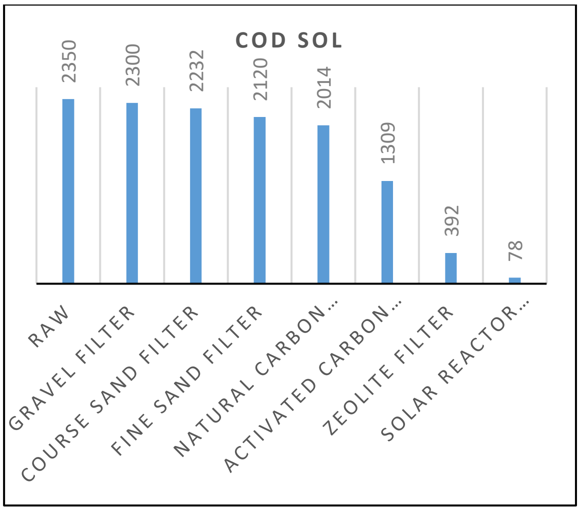

Fig11a Removal of COD- soluble/ filtered, throughout the experiment

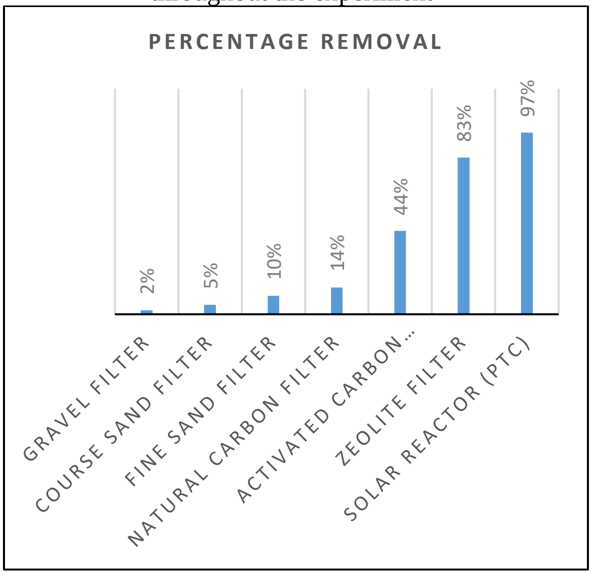

Fig 11 b Percentage Removal of COD-sol variation throughout the whole experiment

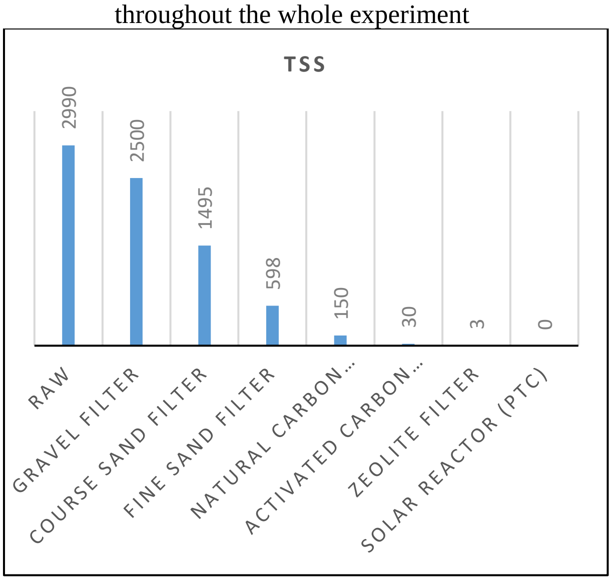

Fig.12 b TSS variation throughout the experiment

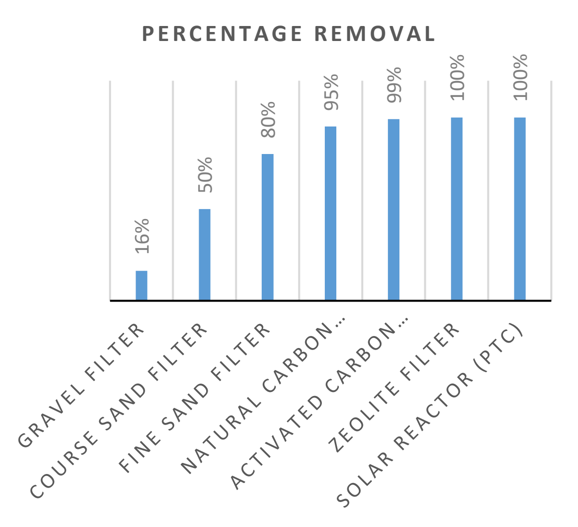

Fig. 12 b Percentage Removal of TSS variation throughout the experiment

5. Conclusion:

The presented system is highly recommended for domestic and industrial wastewaters treatment including the persistent organic pollutants (POPs) that is hardly treated by conventional methods. Physical/chemical pretreatment filters group is representing a very important treatment phase to enhance and facilitate the effective role of the solar reactor. Solar radiation will be very effective in photo-catalytic oxidation process for the samples with very low turbidity. The direct sun light ultraviolet wavelength radiation lies in solar spectrum within the range of 100-400 nm that provides good solar energy potential in hardly degraded waste field. Based on the experimental work and results, the system can achieve remarkable results for all types of pollutants removal starting from non-degradable SS and ending with fine suspended solids. The system in general can provide a highly treated wastewater to be used for WW recycling onsite or to be reusable for all safe activities without any restrictions.

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