

Demonstration of Carbon based Multi-functional and Affordable Water Filters: Sustainable and Compact Drinking Water Facilities for Rural India

Shivaraju Harikaranahalli Puttaiah

Assistant Professor, Department of Water and Health, JSS University, Mysore, India

Corresponding Email: shivarajuenvi@gmail.com

Abstract:

In the present study, Activated carbon based and compact filters were produced using low-cost and indigenous raw materials with active silver, copper, titanium, etc for treatment of drinking water. The properties of filter materials showed unique features, which apparently enhance the purification efficiency. The results clearly indicated that carbon embedded ceramic filters achieved the required drinking water quality standards, which are fixed by the BIS standards within a short duration. Considerable purification efficiency by carbon filters could be attributed due to adsorption and partial ion-exchange nature of core ingredients, redox and disinfection processes of embedded active agents, which resulted in effective removal of pathogens and other pollutants in the water.

Key words: Activated Carbon; Ceramic Matrix; Affordable; Drinking Water Filter; Rural India; Natural Clay.

Introduction:

Research has confirmed that about 10-20 million people die due to waterborne diseases every year [1]. It is also noticed that every day, about 5,000 to 6,000 children die due to water-related problems [1-2]. It is estimated that there are currently more than 0.78 billion people around the world who do not have access to safe water resources, which can lead to major health problems [3]. It is confirmed that more than one billion people in the world lack access to safe water and within a couple of decades the current water supply will decrease by one-third [4]. However, the rapidly increasing population and climate change resulting in prolonged droughts and floods have caused drinking water to be a competitive resource in many parts of the world [5]. Hence there is a need for the development of cost-effective and stable materials and methods for providing fresh water in adequate amounts. It is observed that the traditional water treatment technologies remain ineffective and unable to provide adequate safe water due to increasing demand for water coupled with stringent health guidelines and emerging contaminants. Therefore, nanotechnology-based multifunctional and highly efficient processes are believed provide affordable solutions to water and wastewater treatments techniques without relying on large infrastructures or centralized systems. Nevertheless, providing clean and affordable water to meet human needs is a grand challenge of the 21st century [6-7]. Even though, there are several methods in the market for removal of various contaminants from water resources, they are either expensive or not effective in complete removal of some contaminants [8]. Moreover, nanotechnology is a new area of science that holds great potential in advancing water and wastewater treatment to improve treatment efficiency as well as to augment water supply through safe use of unconventional water sources [9]. Recently organically and inorganically modified clay-based composites have been developed in the form of polymer-clay and metal oxide-clay nano-composites respectively

for water and wastewater treatment. Clays are layered minerals with space in between the layers, where pollutants can adhere to as a result of adsorption site of positive and negative ions or organic molecules, which are present in water [10-12]. Although clays are very useful for many applications, they have one main disadvantage, they lack permanent porosity and permeability. To overcome this problem, researchers have been looking for a way to prop up and support the clay materials with structural pillars and composites. The composite structural pillars could be stabilized filter materials and enhances the stability, porosity, and permeability of clay composites along with multifunctional properties such as antimicrobial and redox processes, which reduce the contaminant loads in water [10-13].

Hence, the aim of this study was to prepare affordable clay-based ceramic filter materials using low cost ingredients. Moreover, to prepare activated carbon using coconut shell and its incorporation along with catalytic and antimicrobial agents in clay-based filter materials for treatment of drinking water, this offers safe drinking water and enables the treatment method in low income or remote areas and in areas affected by natural disasters such as floods or earth cracks.

Materials and Methods

Collection and pre-processing of natural clay and activated carbon

The natural clay material was collected from Krishnaraja Sagara Reservoir Dam situated 12 km from Mysore City, India. Impurities and small rock particles in clay material were separated by submerging it in clean water and constantly mixing it with clean water to form a slurry. The supernatant slurry was separated and allowed to evaporate and dried in a hot air oven before being grinded and sieved to a fine powder. The clay powder was then evaluated using **energy dispersive X-ray** detection to ensure the absence of toxic trace metals contamination. The coconut shells were collected in the university canteen and the husk was scraped off. Later, cleaned coconut shells were broken down into small pieces to be ready for processing and soaked in distilled water to wash off traces of dust and then dried in the hot air oven at 75°C. The dried coconut shell pieces were heated at 1000°C for 3-5 hour in a muffle furnace in the absence of oxygen using airtight metal containers. As-produced black charcoal was activated by soaking it in 1000 ml calcium chloride solution for a day (24 hrs) and then dried. The charcoal was again heated at 900°C for 30 minute using airtight container under pre-heated muffle furnace.

Table 1 Different weight percent ratios of filter materials

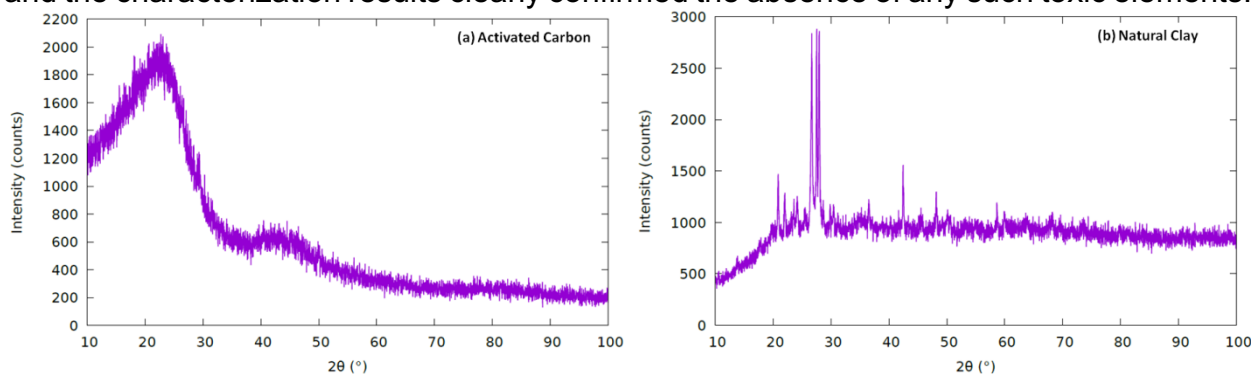
Clay-based filter material	Filter material compositions and amount (in %)					
	AC	Clay	TiO ₂	AgNO ₃	CuSO ₄	Cellulose acetate
FD1	0	93.80	3.35	1	0.17	1.34
FD2	6.70	87.10	3.35	1	0.17	1.34
FD3	10.05	83.75	3.35	1	0.17	1.34
FD4	13.40	80.40	3.35	1	0.17	1.34
FD5	16.75	77.05	3.35	1	0.17	1.34
FD6	20.10	73.70	3.35	1	0.17	1.34
FD7	23.45	70.35	3.35	1	0.17	1.34

Preparation and characterization of clay-based ceramic filter materials

A number of potential ingredients, such as activated carbon and natural clay along with active ingredients such as titanium dioxides (SD Fine Chem., India), copper sulfate (Merck Pvt. Lt., India), and silver nitrate (SD Fine Chem., India) were mixing in different proportions to determine the effectiveness of various combinations of the ingredients. In order to prevent cracking, cellulose acetate (SD Fine Chem., India) was used for the stabilization and strengthening of the cohesion or adherence between the filter material components. The hydrated mixture of activated carbon and natural clay materials of varied amount with the consistent amount of active catalytic agents were thoroughly mixed into a hard paste using double distilled water and molded into cylindrical shaped discs (1.5 cm length and 5 cm diameter) using Teflon molds. Then the filter discs were air dried at room temperature for 24 hour and then dried in hot air oven at 100°C. The dried up filter discs were converted into ceramic porous matrix and stabilized at 900°C under muffle furnace for 6 hour using airtight metal container. Filter discs of various mixing ratios with clay and activated carbon contents were prepared (**Table 1**). The clay-based ceramic filter materials were characterized by analytical techniques like powder X-ray diffraction (XRD), Fourier transmission infrared spectroscopy (FTIR), **scanning electron microscopy (SEM)**, BET surface area and compressive strength.

Results and discussions

Clay-based ceramic filter materials were prepared using low cost ingredients such as natural clay and activated carbon along with active catalytic agents such as copper, silver and titanium dioxide. Utilization of locally prepared activated carbon produced using abundantly available coconut shells and naturally available clay materials as core ingredients to design filters materials enables the production of potential filter materials, which are comparatively cheap. Presence of clay and activated carbon, which are the potential adsorbing agents and ingredients of filter materials can effectively reduce the contamination load and incorporate active agents such as TiO_2 , Ag, and Cu with antimicrobial properties will also potentially minimizes the pathogenic microorganisms in drinking water. Natural clay determined by **energy dispersive X-ray** detection technique in order to ensure the absence of trace metals such as As, Pb, Hg, Se, Zn, B, and Cr; and the characterization results clearly confirmed the absence of any such toxic elements.



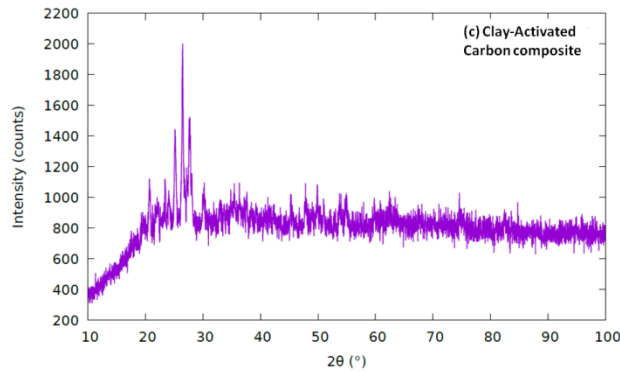


Figure 1 Powder X-ray diffraction of (a) Activated carbon; (b) Natural clay; (c) Clay based ceramic filter materials

The XRD patterns of activated carbon, natural clay, and clay-based ceramic filter disc material are plotted in **Figure 1**. The XRD pattern of activated carbon shows two broad peaks (**Figure 1a**) at 2θ of about 23° and 43° corresponding to the (002) and (100) plane reflection revealing the amorphous nature of the coconut shell based carbon. The XRD pattern of natural clay clearly indicates the presence of different siliceous minerals such as kaolinite, quartz, feldspars, and small fraction of pyrite. Higher intensity of peaks at 2θ of about 25° and 27.5° indicates the well crystalline phase of neomorphic kaolinite and quartz in the natural clay respectively (**Figure 1b**). The XRD pattern of clay-based ceramic filter disc material in **figure 1c** and results clearly showed the presence of well crystalline phases of clay and activated carbon along with TiO_2 (anatase phase), Ag, and Cu, which enhance the catalytic and antimicrobial activities of filter discs.

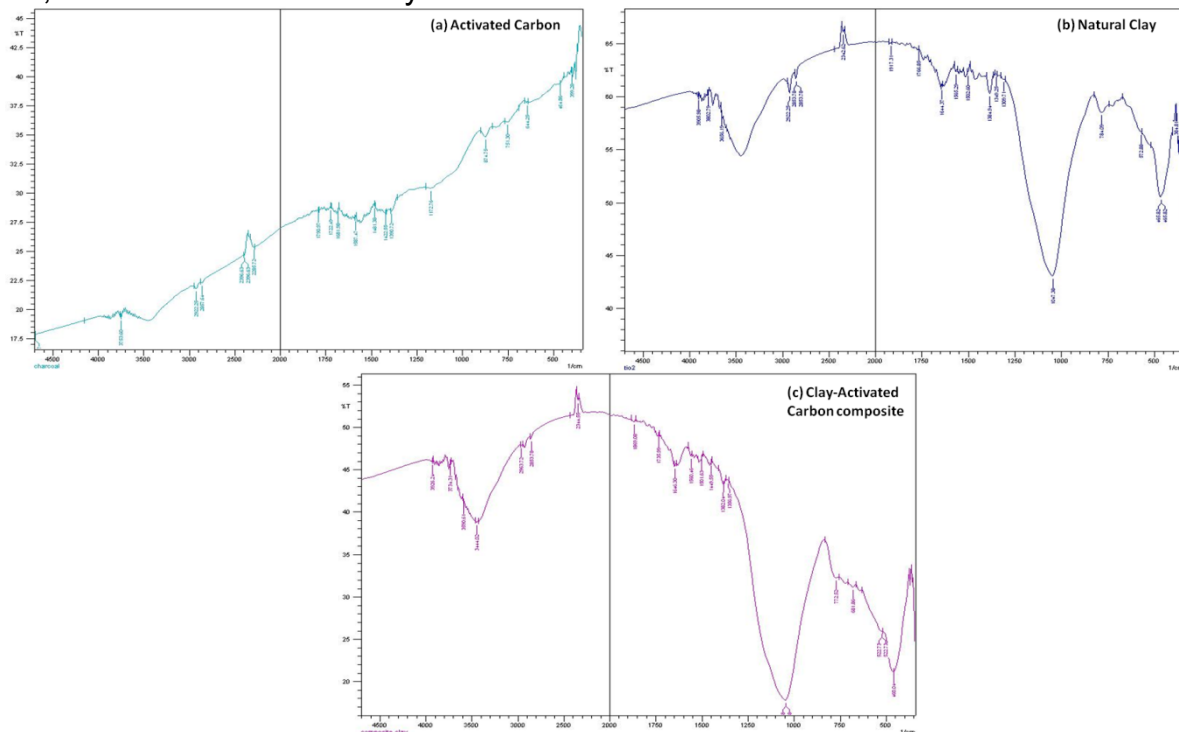


Figure 2: FTIR patterns of (a) Activated carbon; (b) Natural clay; (c) Clay-based ceramic filter materials

Figure 2 shows the Fourier infrared spectroscopic spectra of activated carbon, natural clay, and clay-based ceramic filter materials. The FTIR spectra of activated carbon (**Figure 2a**) shows the peaks of C=C of carbon materials in the range of 1340-1700 cm^{-1} . The absorption peak at 1118 cm^{-1} corresponds to the C-OH stretching and OH bending vibrations, and the peaks at 2921 and 2852 cm^{-1} originate from the C-H stretching vibrations. The peaks at 1580 and 1636 cm^{-1} are due to the stretching vibration of carboxylic group of activated carbon. These results indicate that there are a large number of residues including hydroxyl and carboxyl groups, which play an important role in the formation of pores, which provide a potential avenue to higher surface area and porosity. Figure 2b and 2c show the band observed at 1040 cm^{-1} assigned to stretching vibration of C-F (clay minerals e.g Ti-O-Si) and the band at 1645.30 cm^{-1} is corresponds to deformative vibration of Ti-OH stretching modes. The band at 460 cm^{-1} corresponds to the metal ions and metal oxygenated groups such as TiO_2 , Cu, and Ag, which were used as active ingredients to enhance water treatment efficiency.

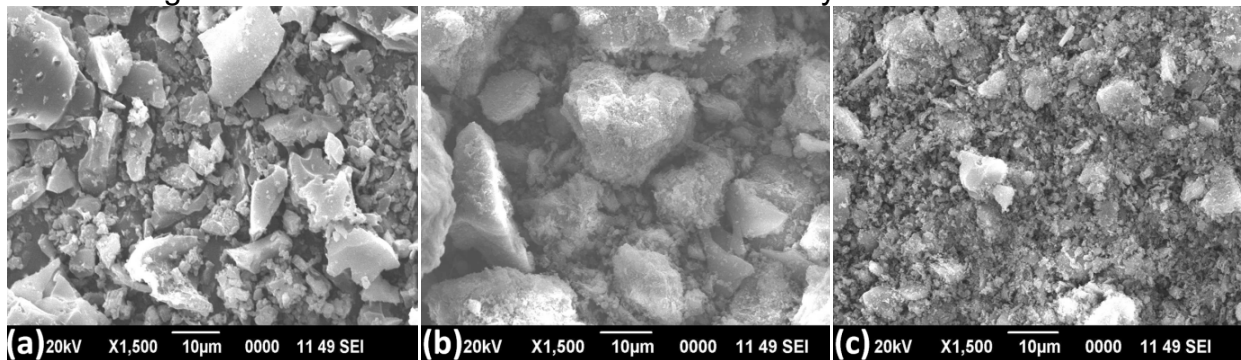


Figure 3: SEM images of (a) Activated carbon; (b) Natural Clay; (c) Clay-based ceramic filter material

The surface morphology of activated carbon, natural clay and clay-based ceramic filters materials are shown in **Figure 3**. All SEM images clearly confirmed more densely populated porosity in activated as well as clay-based ceramic filter than the natural clay. Integration of highly porous activated carbon into the clay along with other active ingredients under high temperature attributed to the increased porosity and it was also confirmed by BET surface area characterization. The BET results clearly indicated that surface area of clay was increased from 99.75 to 144.13 m^2g^{-1} due to the integration of activated carbon and other active ingredients. The raw activated carbon morphological image shows wide gaps of relatively large sized porosities as compared with the pure natural clay materials and the clay-based ceramic filter materials. The clay-based material shows good quality combinations of medium sized and fine porosity suitable enough for potential filtration of drinking water.

Compressive strength test was carried out to know the stability of clay-based ceramic filter discs and result obtained shows the highest compressive strength up to 2600 N in pure clay without activated carbon. However, clay-based ceramic filter discs FD2, FD3, FD4 showed considerable strength values and compressive strength values of clay-based ceramic filter discs with varied weight ratios of activated carbon are presented in **Figure 4**. The filtration rate of a clay-based ceramic filter discs were carried out using deionized water and the results obtained are plotted in **Figure 5**. All filter discs with varied weight ratios of activated carbon showed considerable level of filtration rate from 52-186 m/h , which apparently showed higher filtration rate than typical gravity slow sand filter

bed [14]. Among filter discs, FD5 and FD6 filter discs showed the highest filtration rate due to the attribution of porosity and adhesiveness of activated carbon.

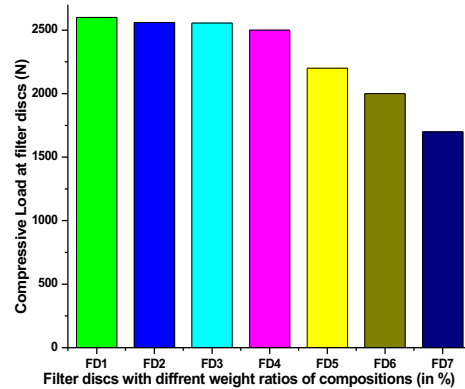


Figure 4 Compressive load at clay-based ceramic filters discs with varied weight ratios of activated carbon

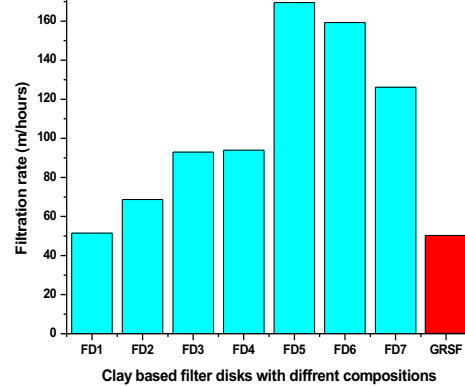


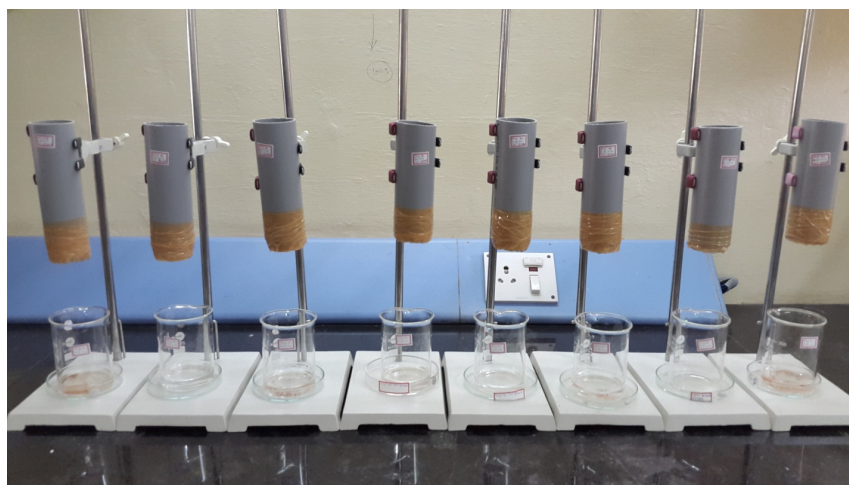
Figure 5 Filtration rates of clay-based ceramic filters discs with varied weight ratios of activated carbon

Practical evaluation of the treatment efficiency of clay-based ceramic filter discs in water filtration processes were carried out and purification level was compared with drinking water standards. Important chemical and biological parameters, which play an important role on human health were considered to evaluate the clay-based ceramic filter discs efficiency in the treatment of drinking water. The results obtained indicate the considerable reduction of all type of contaminant during the filtration through clay-based ceramic filter discs under gravity (**Table 2**). Moreover, important water quality parameters such as nitrite, nitrate, total dissolved solids (TDS), and total hardness (TH) were considerably reduced to permissible limits for drinking water after filtration through clay-based filter discs. Considerable reduction of chemical oxygen demand (COD) level after filtration was attributed to the potential adsorption and filtration of organic compounds by activated carbon and clay. Reduction of COD level in the filtered water indicated that tremendous removal of organic pollutants due to filtration through micro-pores of ceramic filter disc and adsorption by activated carbon as well as clay, which are the major ingredients of filter disc. The result obtained also indicated significant reduction of microbial load in the filtered water and the presence of antimicrobial agents such as TiO_2 , Cu, and Ag at trace levels enhances the antimicrobial properties of clay-based filter disc. The research indicated average removal efficiency for total coliform bacteria from drinking water in all the filter discs regardless of the compositional mixing and weight ratios. Clay-

based ceramic filter discs such as FD2 and FD3 showed comparatively higher MPN number due to the less compositional content of activated carbon. Structural variety in porosity of filter materials does not influence the removal of microorganisms as both size grades and composites with no activated carbon performed equally.

Table 2 Removal efficiency of chemical and bacterial contaminants from drinking water using clay-based ceramic filter discs

Clay-based ceramic filter discs with varied weight ratios of activated carbon	Water quality parameters (in ppm) and Total coliform bacteria (MPN No/100 ml)					
	Nitrite	Nitrate	TDS	TH	COD	MPN No.
Initial Values	2.8	51.75	957	443.5	180	1100
FD1	0	17.25	560	227.5	60	210
FD2	0	8	510	210	55	460
FD3	0	8.25	569	205	35	460
FD4	0	13.25	539	202.5	80	240
FD5	0.04	10.1	484	222.5	80	240
FD6	0.53	11.9	471	195	90	240
FD7	0.68	12.5	497	277.5	50	240
Desirable amount for drinking purposes	0.5	45	500	300	NA	10



Conclusion

Affordable and durable clay-based ceramic filter discs were designed using low cost materials such as natural clay, activated carbon and other metal oxide based active agents. Characterization results revealed that a well crystalline structure, high porosity and permeability, considerable surface area and structural elucidation of ceramic filter material will intensify the removal of contaminants in drinking water during filtration through clay-based ceramic disc under gravity. Natural clay collected from local lake and locally produced activated carbon were found to be an effective and low cost ingredient for the designing of affordable and durable filter materials. Moreover, utilization of locally produced activated carbon along with other active agents tremendously increased the removal efficiency of organic contaminants and pathogenic microorganisms from the

drinking water. Exceptional features of clay-based ceramic filter materials such as stability, durability, incorporated with low cost and abundantly available raw materials, potential treatment efficiency, etc., have made it an affordable material for potential treatment of drinking water in poor, remote and catastrophic areas.

References:

- [1]. Wang, X., Guo, Y., Yang, L., Han, M., Zhao, J., and Cheng, X. (2012), Nanomaterials as Sorbents to Remove Heavy Metal Ions in Wastewater Treatment. *J Envi Anal Toxicol.*, 2-7.
- [2]. Farrell, J. W., Fortner, J., Work, S., Avendano, C., Gonzalez-Pech, N.I., Araiza, R. Z., Li, P. Q., A'lvarez, J. J., Colvin, V., Kan, A., & Mason, T. (2014), Arsenic Removal by Nanoscale Magnetite in Guanajuato, Mexico. *Environmental Nanomaterials. Envi Engine Scie.*, 31(7):393-401.
- [3]. Gayathri, G., Maheshwari, U. and Gupta, S. (2012), Application of Nanomaterials for the Removal of Pollutants from Effluent Streams; *Nanosci Nanotech- Asia.*, 2(2):140-150
- [4]. Gautam, P., Madathil, D., & Brijesh, A. N. (2013) Nanotechnology in Waste Water Treatment: A Review School of Bio Sciences and Technology, School of Mechanical and Building Sciences, VIT University, Vellore, Tamilnadu, India – 632014.
- [5]. Amin, M. T. Alazba, A. A. and Manzoor, U. (2014), Review Article: A Review of Removal of Pollutants from Water/Wastewater Using Different Types of Nanomaterials. *Adv Mat Scie Engine.*, 825910: 1-24.
- [6]. Magnhild, F. (2005), Wastewater Treatment in Filter Beds, Common Report from all Pilot Plants. Nordic Innovation Centre (NICE).
- [7]. Chien-Chen, W. and Dong-Hwang, C. (2012), Spontaneous synthesis of gold nanoparticles on gum Arabic-modified iron oxide nanoparticles as a magnetically recoverable nanocatalyst. *Nanoscale Res Lett.*, 7:317-412.
- [8]. Prachi, P. G., Madathil, D. A. N. & Brijesh, N. (2013), Nanotechnology in Waste Water Treatment: A Review, In *J Chem. Tech Res.*, 5(5):2303-2308.
- [9]. Christian, N. & Marcel, V. V. (2014), Nanotechnology in a nutshell, *Nanomaterials: doing more with less*,
- [10]. Lichtfouse, E., Schwarzbauer, J., and Robert, D. (2005) *Environmental Chemistry, Green Chemistry and Pollutants in Ecosystems*. Springer Berlin Heidelberg New York
- [11]. Mohammed, A., Fengting, Li., and Wang, H. (2013) Application of Natural Clays and Poly Aluminium Chloride (Pac) for Wastewater Treatment. *I J Recent Res Appl Studies.*, 15(2):287-291.
- [12]. Tom, N. K., Sivan, S., and Giora, R. (2012) Brine wastewater pretreatment using clay minerals and organoclays as flocculants, *Appl Clay Science.*, 67:119–124.
- [13]. Gomez-P. J., Bringas, E., and Inmaculada, O. (2014), Recent progress and future challenges on the use of high performance magnetic nano-adsorbents in environmental applications. *J Chem Engine.*, 256:187–204.
- [14]. Centre for Affordable Water and Sanitation Technology (2012), household water treatment: slow sand filter, DFWED, 1-2.