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Synthesis of iron doped zeolite nanocomposite: one step treatment of drinking water for biological, inorganic and organic contaminants

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ABSTRACT

Low cost filter, based on iron doped zeolite and pottery clay, was developed for an effective and efficient treatment of the drinking water contaminated with biological, inorganic (both cationic and anionic) and organic contaminants. Iron nanoparticles doped zeolite was characterized using powder XRD, SEM and EDX and shown to have an average particle size of 38.4 nm with spongy appearance. The simulated samples of water self-contaminated with microbes (*S. typhi, B. subtilus, E. coli, S. aures* and *P. aeruginosa*), organic (cypermethrin, dioctylphthalate and reactive red RB dye) and inorganic pollutants (arsenic, lead, chromium, nitrate, phosphate, fluoride) after treatment with 0.1 g of iron doped zeolite showed effective removal of all the contaminants in less than 30 min. Equally good results were obtained when actual drinking water samples that were totally unfit for human consumption (Colony Forming Unit (CFU) values above the WHO permissible limits) were treated with iron doped zeolite and after treatment these samples have their CFU values lie within 0–9 CFU/mL. The filter was also checked for its adsorption capacity and results showed appreciable decrease in total hardness and conductivity of treated water samples. The present discovery is better, effective and low cost and therefore can easily be applied as filter in water filtration units for provision of safe and health drinking water to public.

Keywords: Biological treatment; Chemical treatment; Drinking water; Iron-doped zeolite; Pollutants removal; Pottery clay

1. Introduction

Clean water, a prerequisite for safe and healthy life, is continuously facing a decline in its quality due to rapid industrialization, urbanization and population growth [1]. The journey to the heights of development and modern societies had no doubt bestowed human with many life amenities, but during this course environment remains the most affected part. Fresh water reserves which were already 3% of the total water available are now scarce as a result of industrial as well as domestic activities. Among these, the major issue that is in concern now a days, in both developed and under-developed countries, is the presence of waterborne pathogens that are becoming resistant to the already known methods of their removal and hence are now available to cause severe infections and with much less number [2,3]. Similarly, introduction of other pollutants both inorganic and organic that enter into water system from industrial and agricultural activities pose

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major health impacts as well as environmental issues [4–8]. In this regard adsorption remains the method of choice due to its low cost and easy approach. Many adsorbents have been used but those obtained from natural sources are preferred due to their benign nature, these include agricultural wastes, peals or shells of fruits and vegetables, zeolites, clays, etc. [9]. Zeolites owing to their highly porous structure is gaining significant attention in environmental applications especially water and waste water treatment [10]. They have been frequently used for the removal of inorganic and organic contaminants either by using them as such or employing modifications on surface as well as within structure [10–12]. There are not much citations for the antimicrobial properties of these pure zeolite materials and hence to impart antimicrobial nature to this zeolite structure the incorporation of metal and metal oxides is a common practice [13,14]. In-spite of all these modifications the conventional methods of treatment [3,15] have no longer remained effective, therefore strive to develop new methods had led researchers to focus their attention to nanotechnology [16–18].

In this regard many nanomaterials were researched that can be used to decontaminate the water from microbial, inorganic or organic contaminants hence offering a cost effective and green way of treating water [16]. Pesticides, arsenic, lead, fluoride are pointed as major contaminants [19] while phthalates and dyes have endocrine disrupting abilities [20]. Several nanoparticles like Ag(0), TiO_2, ZnO etc. are found effective in treatment of waterborne microbes with bactericidal (bacteria-killing) and/or bacteriostatic (bacteria-inhibiting) nature causing microbial cell wall [17,21,22]. Among these, only TiO_2 has been employed as a preferred material for catalytic degradation and adsorption of waterborne contaminants [23–25]. But for TiO_2, the UV light irradiation is must to induce its photocatalytic properties and is also found to be ineffective against *E. coli* in lower doses [23,24,26]. Further, TiO_2 alone is not a good adsorbent for fluoride though its modified forms show better adsorption capacities but have limitations as application for direct use in packed bed columns [27]. Nano-zeolites have also been used for the adsorption of nitro-phenols [28] and lead [28] but much improved adsorption capacities towards different contaminants have been recorded by introduction of nanoparticle in these zeolites. Nevertheless, majority of these studies deal with single type contaminant removal that is either inorganic or organic or bacteria. Hence, there is a need to design new materials (Table 1) that can effectively decontaminate drinking water from the various types of contaminants in a single step without using tedious and long procedures. These materials should have the potential to decontaminate the water from waterborne pathogens as well as able to remove the inorganic contaminants both cations and anions and degrade organic pollutants.

2. Material and methods

2.1. Materials

The materials used during the study are of analytical grade and procured from Sigma Aldrich except sodium borohydride which was purchased from BDH. Doubly distilled water was employed throughout the studies.

2.2. Microbial strains

Escherichia Coli ATCC 10536, *Bacillus subtilis* ATCC 11774 *and Staphylococcus aureus* ATCC 12600 were purchased from Microbiologics, Pakistan. *Salmonella typhi* and *Pseudomonas aeroginosa* were procured from the University of Veterinary

Table 1
Nanomaterials for the treatment of water pollutants

Nanomaterial	Contaminant	Adsorption capacity	Reference
PVP-Zinc peroxide	CN^{-1}	–	[67]
Graphene – Titanium oxide	Naphthalene, toluene, diesel	–	[68]
$Co^{+2}Mo^{+6}$ Layered double hydroxide	Pb (II)	73.4 mg/g	[69]
3D graphene	Desalination	18.43 mg/g	[70]
$MnWO_4$ nanoflowers	*E. coli*	10 µg/ml (MIC)	[71]
Polyvinyl-clay	Pb (II)	70.42	[72]
Fe/Ni	Pentachlorophenol		[73]
N-Doped TiO_2-Coated Ceramic Membrane	Carbamazepine	–	[74]
3D $MnWO_4$–TiO_2 nano-flowers	Methyl orange	95%	[75]
Zeolite Nano-Particles Impregnated Polysulfone Membranes	Pb (II), Ni (II)	682, 122 mg/g	[76]
NiO NPs/A-clinoptilolite zeolite	U (VI)	23.58 mg/g	[77]
Nano-zeolite	o-, p- and m-nitrophenols	125.7, 143.8, and 156.7 mg/g	[28]
Zeolite-Palladium nano-fiber	NH_3-N	92.2%	[78]

and Animal Sciences, Lahore, Pakistan and were then sub-cultured on Nutrient Agar (Merck, Germany) and Sabouraud Dextrose Agar (SDA Merck, Germany) and incubated aerobically at 37 °C for 24 h.

2.3. Synthesis of iron doped zeolite (Fe-Z)

2.3.1. Preparation of zeolite (NZ)

Sodium silicate solution (220 g of 20º Baume/330 mL distilled water) was taken in a three-necked quick fit round bottom flask fitted with reflux condenser and two dropping funnels and heated to 50–60ºC followed by addition of ethylene glycol (25 mL) as templating agent. The contents of flask were stirred for 30min while maintaining temperature at 50–60ºC in order to get a homogeneous mixture. To this solutions of aluminum sulphate (8.0 g/500 mL) and sodium hydroxide (30 g/500 mL) were added drop-wise separately from two dropping funnels. During addition the reaction mixture was stirred vigorously. After complete addition of both the solutions, the contents of flask were refluxed for 7–8 h followed by addition of dil. HCl until pH was maintained at 7–8. The contents of flask were then stirred for another 2–3 h, while maintaining temperature at 70–80ºC. Afterwards, the contents were allowed to cool to room temperature, filtered and washed with distilled water in order to remove any impurities. The residue which was obtained after filtration is first air-dried and then placed in oven at 120–130ºC followed by calcination in furnace at 650ºC for 3–4 h resulting in grey colored zeolite which was kept in air tight jar until further use.

2.3.2. Preparation of iron doped zeolite (Fe-Z)

Added $FeCl_2{\cdot}4H_2O$ (1.5 g/500 mL distilled water) into two-necked quick fit round bottom flask containing 25 g zeolite (prepared in previous step) and fitted with inert line and dropping funnel containing $NaBH_4$ (2 g/100 mL distilled water). The contents of the flask were stirred vigorously at room temperature during the drop-wise addition of $NaBH_4$ solution. After complete addition, the reaction mixture was filtered and washed with distilled water to remove impurities and unreacted reactants. The residue was first dried in air followed by oven heating at 200ºC. The prepared Fe doped zeolite was kept in air-tight jar until further use.

2.4. Preparation of standard solutions and spiked samples

Microbes simulated samples: Simulated water samples were prepared by spiking distilled water (pre-checked for 0 CFU) with common water borne pathogens (*E. coli*, *S. aureus*, *P. augenase*, *S. typhae* and *B. subtilis*). Maximum of four colonies of 24 h old culture of selected bacteria were then touched with the sterile loop from each plate and they were then transferred to distilled water under aseptic conditions with density of each suspension being equal to that of 10^6 Colony Forming Unit (CFU/mL) standardized by 0.5 McFarland standard and this was further used as inoculum [29]. After that the bottles were kept at room temperature for 24 h in order to get maximum bacterial growth.

DOP simulated sample: DOP 1000 $mg{\cdot}L^{-1}$ solution was prepared in methanol, from this 10 $mg{\cdot}L^{-1}$ working solution was prepared in distilled water and kept in refrigerator at 4ºC till further use [30].

CM simulated sample: CM 1000 $mg{\cdot}L^{-1}$ solution was prepared in acetone, from this 10 $mg{\cdot}L^{-1}$ working solution was prepared in distilled water and kept in refrigerator at 4ºC till further use [31,32].

Stock and working solution of reactive red RB dye: 1000 $mg{\cdot}L^{-1}$ stock solution of RD was prepared in doubly distilled water and from it working solutions of 10 $mg{\cdot}L^{-1}$ was prepared by dilution.

Stock and working solutions of As, Pd and Cr: 1000 $mg{\cdot}L^{-1}$ stock solution of As, Pb and Cr were prepared from As_2O_3, $Pb(NO_3)_2$ and $K_2Cr_2O_7$ in doubly distilled water, respectively. From these working solutions of 100 $mg{\cdot}L^{-1}$ were prepared by dilutions of respective stock solutions.

Stock and working solutions of nitrate, phosphate and fluoride: 1000 $mg{\cdot}L^{-1}$ stock solution of NO_3^{-1}, PO_4^{-3} and F^{-1} were prepared from $NaNO_3$, $NaH_2PO_4{\cdot}2H_2O$ and NaF in doubly distilled water, respectively. From it working solutions of 100 $mg{\cdot}L^{-1}$ were prepared by dilutions of respective stock solutions.

2.5. Antimicrobial activity

For antimicrobial activity the simulated water samples were taken that were spiked with common water borne pathogens (*E. coli*, *S. aureus*, *P. augenase*, *S. typhae* and *B. subtilis*). 100 µL of inoculum was then spread on the specific media plates to achieve a confluent growth. Plates were then allowed to dry and then incubated aerobically at 37ºC for 24 h. After 24 h the CFU/mL was counted against each microbial strain by the method of Breed and Dotterrer, 1916 [33].

The antimicrobial potential of prepared materials were analyzed by taking 50 mL of the simulated samples in 100 mL quick fit round bottom flask containing 0.1 g of the undoped zeolite and Fe-Z. The contents of the flask were allowed to remain in contact for different time periods (10–120 min) and analyzed for bacterial activity (CFU mL^{-1}) after canola filtration following the same approach as used for spiked water samples.

2.6. Catalytic and adsorption activities

For checking the catalytic and adsorption properties of Fe-Z, independent experiments were carried out by taking 25 mL of 10 $mg{\cdot}L^{-1}$ of organic (α-cypermethrin (CM), dioctylphthalate (DOP) and reactive red RB dye (RD)) and 100 $mg{\cdot}L^{-1}$ inorganic (arsenic, lead, chromium, nitrate, phosphate, fluoride) pollutants in a round bottomed flask containing 0.1 g of Fe-Z. The contents of flask were stirred for 30 min at room temperature; canola filtered (mention filter paper pore size) and analyzed using respective instruments as described in characterization. The results hence obtained were compared with undoped zeolite.

Before GC analysis, DOP was extracted from aqueous samples in chloroform (10 × 3) using separatory funnel. Each time the chloroform layer was collected by passing through the funnel filled with anhydrous sodium sulphate supported on glass wool. The chloroform extract was rotary evaporated at 40ºC to dryness and final volume was marked to 50 mL with hexane before analysis [34]. Similarly, CM was extracted in dichloromethane using the same protocol, except that prior to extraction 10 mL of 4% NaCl solution was added to aqueous samples to facilitate separation [32].

2.7. Filter disc formation with pottery clay (Fe-Z-PC)

The filter bed or disc was prepared with the help of mixing Fe-Z (5g), pottery clay (50 g) and finally grinded saw dust (0.1 g) in the high-speed grinder. The resulting material was palletized into a disc (3″ diameter and 1/2″ width) and soaked overnight in distilled water. This soaked pallet was kept in furnace at 650ºC for 3 h in order to form perforated disc. The disc was then further checked for its efficacy for the treatment of contaminated drinking water samples.

2.8. Tap water treatment

Water physico-chemical parameters were also determined after treatment with the prepared Fe-Z. The parameters accessed are pH, conductivity, total hardness, calcium ions and magnesium ions. The usual protocols were obeyed for determining these parameters [35].

Each parameter was analyzed before and after treatment of the 50 mL sample with 0.1 g of Fe-Z while for Fe-Z-PC the disc was dipped for 24 h in 100 mL sample of contaminated drinking water.

2.9. Characterization

Zeolite and Fe doped zeolite were characterized using FT-IR, SEM and EDX. The FT-IR spectra were collected at Thermo Nicolet spectrometer series by scanning the sample pallet made with KBr in the range of 4000–400 cm^{-1} while SEM/EDX images and data were recorded using S3700N, Hitachi, Japan. Powder XRD was carried out using PANalytical in the scan range of 5.0000–120.0000º using continuous mode and step size of 0.0250º.

pH and conductivity measurements were taken by using HANNA instruments. For CM and DOP, Varian gas chromatograph (GC) CP-3800 with software version 1.9 equipped with electron capture detector (ECD) and DB-5 column (30 m × 0.25 mm i.d. × 0.25 µm film thickness) was employed. The column temperature was programmed at 50ºC (held for 1 min) at 30ºC min^{-1} to 205ºC (1 min) and then 1ºC min^{-1} to 240ºC (10 min). Injector and detector temperature in both cases were kept at 280ºC and 300ºC. The carrier gas flow was set at 6 mL/min while keeping the same makeup flow. For determination of RD and phosphate UV/V is spectrophotometer Analytikjena Specord 200 was used at wavelength 515 and 400 nm (molybdovanadate method [36]), respectively. Arsenic concentration was determined using Arsenic kit purchased from Merck while lead and chromium were determined using Flame atomic absorption spectrometer (FAAS)-Spectra AA220, Varian Inc. (Australia). Nitrate and fluoride were analyzed using ion electrode 930, Spectrum, Scientific, UK.

3. Results and discussion

The Fe-Z nanomaterial was synthesized with the aim of preparing a low cost material that can be used in filtration assemblies for purification of drinking water. Both iron nanoparticles and zeolites have earlier on proved to have enhanced antimicrobial activities [37,38].

3.1. Synthesis of doped zeolite

The synthesis of doped zeolite involved the reduction of Fe^{+2} to Fe^0 by $NaBH_4$ used as reducing agent. The reaction takes place as follows:

$$\mathrm{Fecl_2 / Zeolite + 2NaBH_4^- + 6H_20 \rightarrow}$$
$$\mathrm{Fe^o / Zeolite + 2NaCl + 2B(OH)_3 + 12H_2}$$

As a result of reduction, Na^+ ions present in the framework of zeolite will be replaced by Fe^o hence resulting in formation of Fe-Z as in accordance with earlier studies [39].

3.2. Doped and undoped zeolite characterization

For characterization of doped and undoped zeolites FT-IR, powder XRD, SEM/EDX, BET surface area and pore distribution analysis were conducted.

Fig. 1 shows comparison of FT-IR spectra for the zeolite and Fe-doped zeolite. In case of undoped-zeolite vibration bands were observed at 3410 cm^{-1} for O–H stretching, due to O–H bond stretching (H bonding) either due to water incorporated in porous structure of zeolite or due to Si-OH. The band appearing at 1635 cm^{-1} was attributed to H-O-H bending while the one strong band appearing at 1101 cm^{-1} corresponds to Si-O and other inter-structure bands remained unchanged; it was associated with the stretching vibration of Si-O, which usually suggests a three dimensional silica phase. The band at 676 cm^{-1} was assigned to the Al-O bending vibration [40–42]. The FT-IR spectra indicated the rigidity of silicate structure and nonband chemical interaction between the zeolite structure and Fe-doped zeolite. The interactions between the zeolite and Fe-Z were associated with the peak at 3471 cm^{-1}. A broad peak was due to the presence of van der Waals interactions between the hydroxyl groups in the zeolite structure related to H_2O and the partial positive charge on the surface of Fe nanoparticles.

Powder XRD patterns of the zeolite and Fe-Z are presented in Fig. 2. The pattern of NZ shows the presence of eight peaks at 2θ values of 6.20º, 21.77º, 28.34º, 31.41º, 35.94º, 46.81º, 48.39º, 56.68º and 64.89º. The base peak being recorded at 6.20º which is characteristic of the faujasite (FAU) like zeolite pattern reported by earlier scientists [43,44]. The results are also in accordance with the pattern observed for high Si/Al ratio [40,41]. After doping, there is small shifting in the peaks along with the appearance of new peaks owing to presence of doped iron with some traces of iron oxide as well. The peaks recorded in this case have 2θ values as: 6.26º, 21.84º, 28.29º, 31.64º, 36.03º, 42.47º, 45.75º, 46.80º, 48.39º, 56.43º, 64.65º and 75.25º. The peak recorded at 45.47º (marked with * in Fig. 2) was attributed to the iron (reference CCDC 00–003–1050). This is also in accordance with earlier studies conducted for Fe/ZSM-5 [45]. The broadening of peaks in both the cases points towards the formation of nanosized materials [46].

Debye Scherer equation was employed to calculate the particle size of the materials synthesized. The average

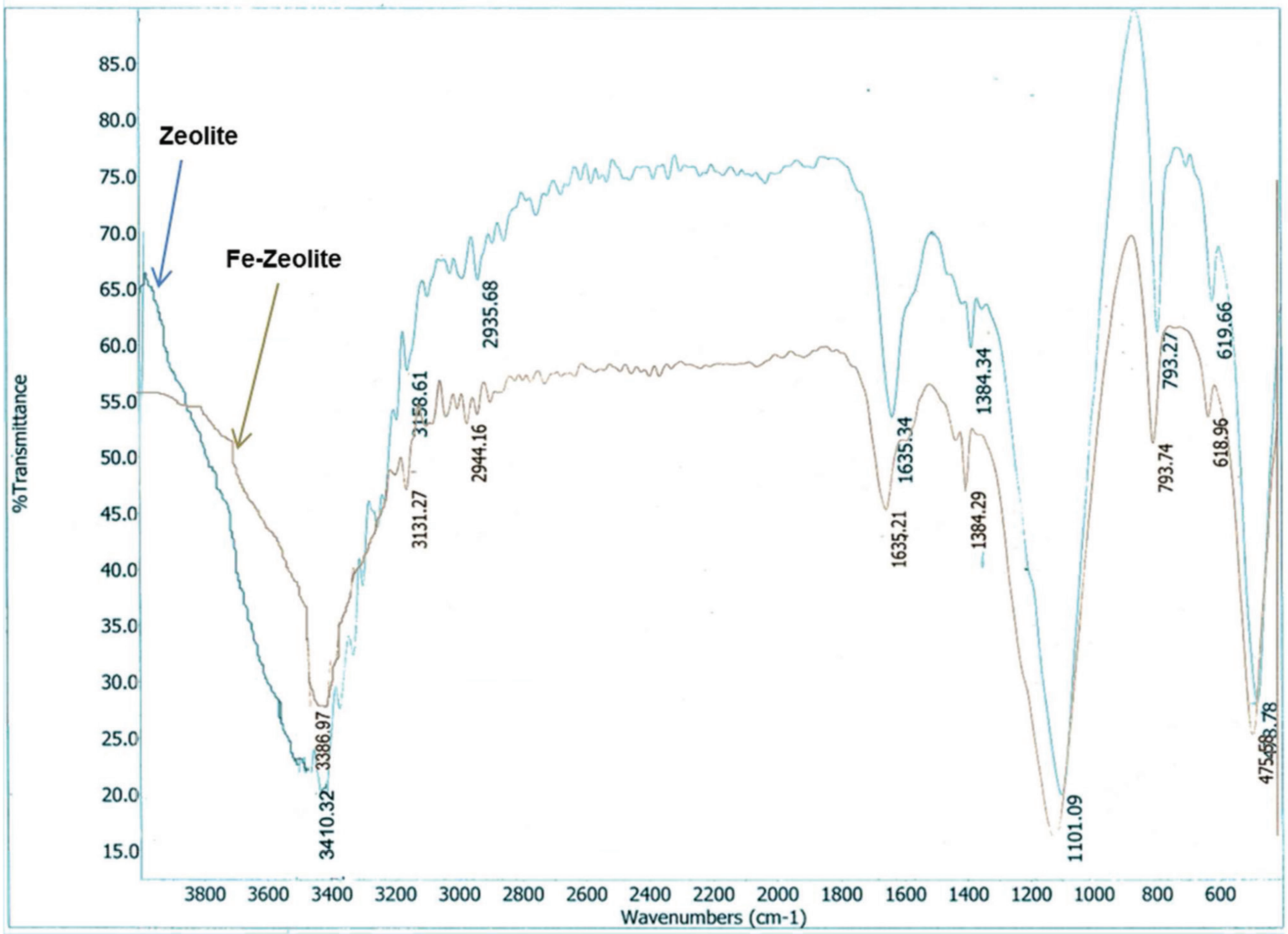

Fig. 1. FT–IR spectra of doped and undoped-zeolite.

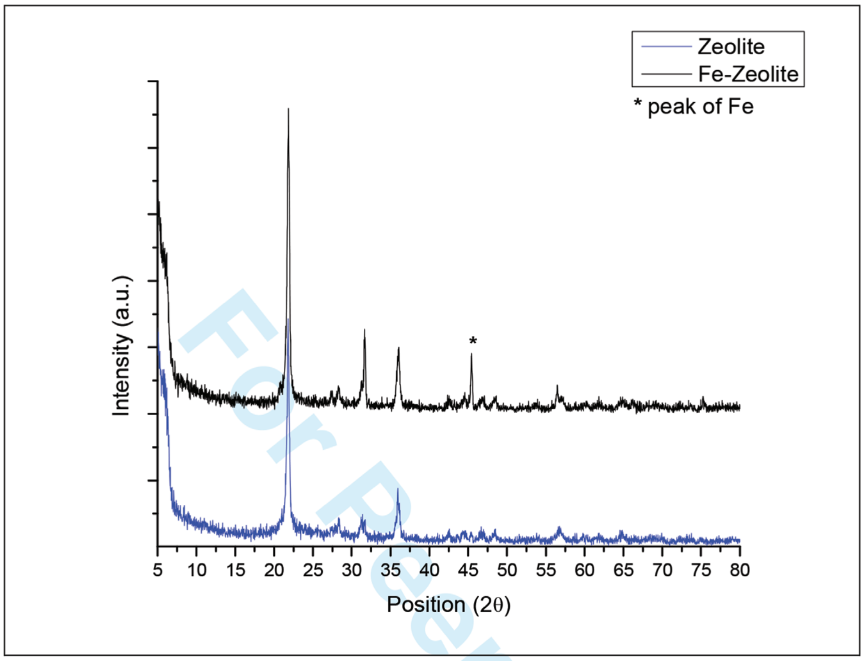

Fig. 2. Powder XRD patterns of undoped and doped zeolites, * marks the peak due to iron.

particle size calculated for the doped zeolite was 25.3 nm while that of the undoped zeolite is 38.4 nm.

SEM images were also taken for the doped and undoped-zeolite to have insight into the morphologies of the materials. The images (Fig. 3) demonstrated that the zeolite formed is quite porous in nature (Fig. 3a) and underwent significant decrease in particle size after doping (Fig. 3b) as also confirmed from particle size studies done using powder XRD. Moreover, the BET surface analysis depicted considerable increase in the surface area of doped zeolite which increases from 13 to 114 m^2 g^{-1} as also indicated by studies on zeolite doping by previous researches [47]. Similarly, after doping the BJH pore distribution is significantly changed; the average pore size changes from 204.85 to 35.72 nm. Further, metal doping induced defects into the zeolite structure which enhances the adsorption capacity of the zeolite along with imparting reactive sites.

The elemental composition of the pottery clay, undoped and doped zeolite was established by EDX (Fig. 3). The molar ratio of Si/Al in case of undoped zeolite was found to

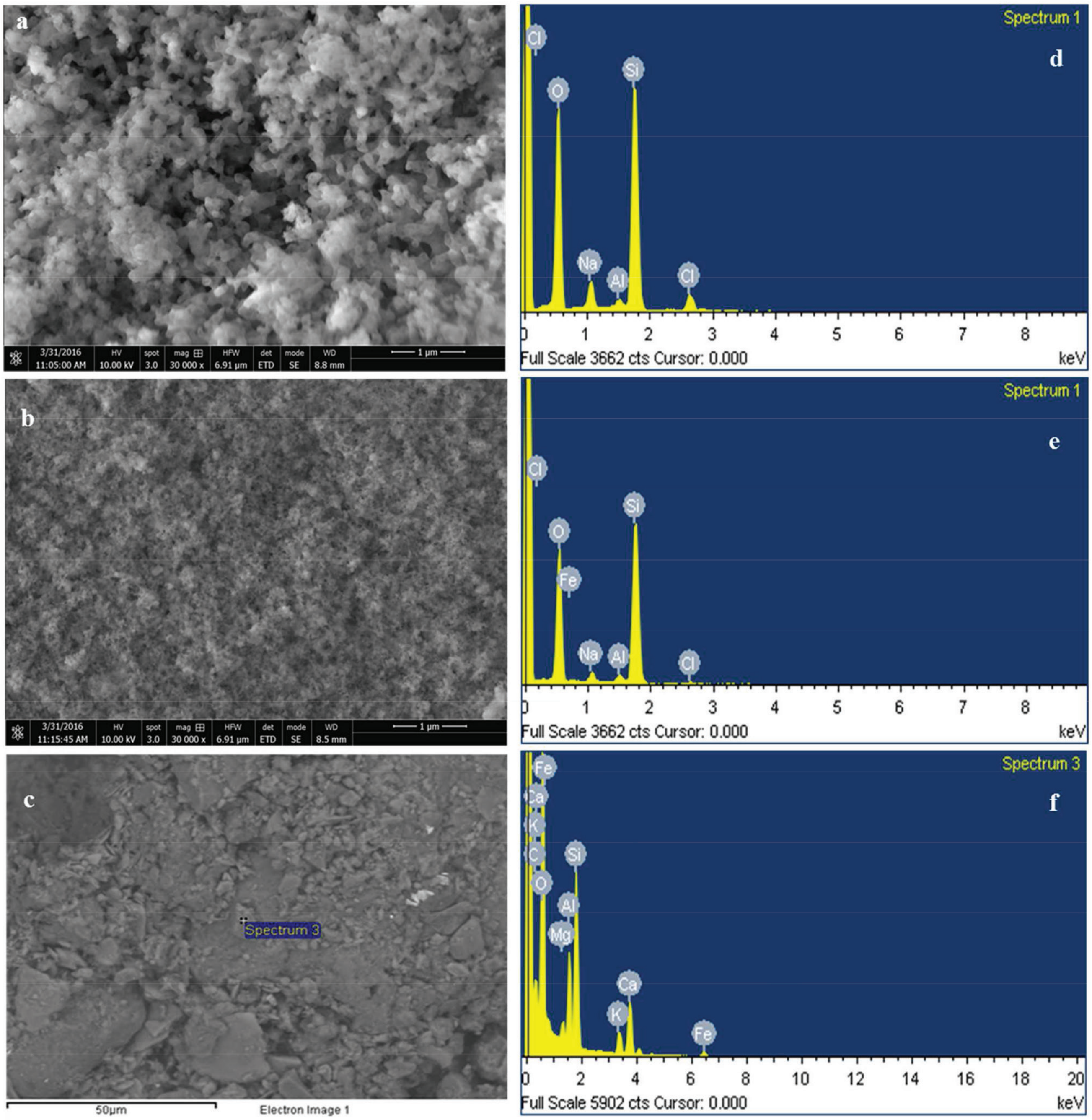

Fig. 3. SEM images of (a) NZ, (b) Fe-Z, and (c) pottery clay along with EDX analysis of (d) NZ, (e) Fe-Z, and (f) pottery clay.

be 46.15 which decreased to 34.15 in case of doped zeolite. The high Si/Al ratio observed is in accordance with powder XRD results as also indicated by earlier studies [40,41]. Further, the doping of iron (2.01%) is confirmed with EDX analysis. In addition to Na, Si, Al, O in case of zeolite and Fe doped zeolite, there are minor impurities of Cl which might be due to the use of hydrochloric acid used for neutralizing the sample as mentioned in experimental portion. Earlier studies carried out had also confirmed the presence of doped moieties using EDX analysis [48–50].

3.3. Anti-microbial studies

Antimicrobial activity of Fe-Z and NZ was checked against both gram positive and gram negative bacteria (*S. typhi, B. subtilus*, *E. coli*, *S. aures* and *P. aeruginosa*) that are known to be the key source for majority of waterborne diseases. The bacterial removal efficiency was checked by comparing the concentrations (Log$_{10}$ CFU/100 mL) of target organisms before and after treatment with the Fe-Z and NZ for varied time periods. Microbes were detected and enumerated from water samples according to Standard Methods [51]. The results, tabulated in Table 2, indicated that there is considerable decrease in the CFU values of all the microbes contaminated samples in case of doped zeolite as compared to the undoped ones. High bacterial growth with undistinguished colonies was observed for untreated samples (zero contact time; Table 2) spiked with *S. typhi, P. aeruginosa* and *B. subtilis* which after treatment with Fe-Z resulted in remarkable decrease in microbial growth (Fig. 4a). In rest of the two cases, i.e., *E. coli* and *S. aureus* steady decrease in CFU was observed with increase in contact time with Fe-Z (Fig. 4b). Overall in each case optimum contact time was observed to be 30 min after which there is no substantial decrease in the CFU values (Table 2). Further, experiments conducted up to 48 h showed that Fe-Z reduces the regrowth of bacteria as well thus proving the bacteriostatic effect of the prepared material. The results are much more promising as compared to the earlier used iron nanoparticles that have shown considerable reduction in the antimicrobial activity under air saturation owing to its surface oxidation [37].

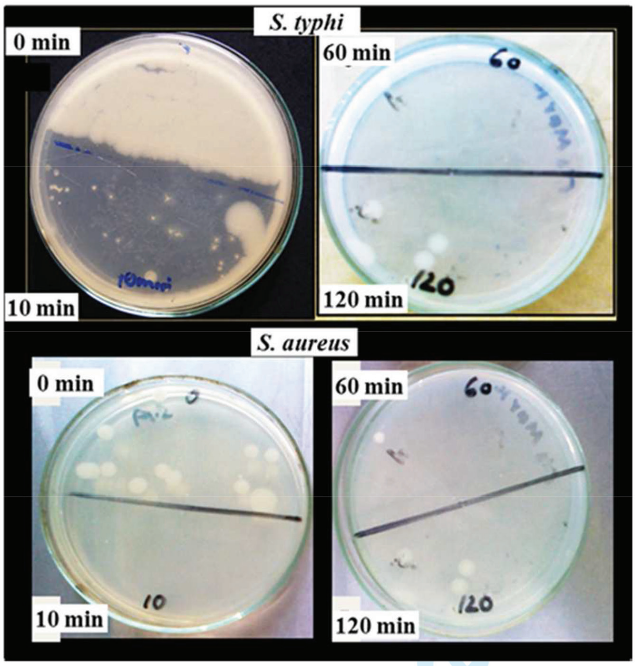

Fig. 4. The effect of different contact time of Fe-Z on *S. typhi* and *S. aureus*.

In general, nanoparticles interact with microorganisms resulting in the decrease of CFU. This interaction can be through different mechanisms, e.g., direct interaction with the microbial cells, interruption of trans membrane electron transfer, cell components' oxidation, disruption/penetration into the cell envelope or by producing secondary products that cause damage [52].

Table 2
Colony count data of simulated samples contaminated with different bacterial strains before and after treatment with iron doped zeolite for varied contact time

Contact time (min)	CFU/mL values of microbes contaminated water									
	E. coli		*S. aureus*		*S. typhi*		*P. aeruginosa*		*B. subtilis*	
	Fe-Z	*Z*	*Fe-Z*	*Z*	*Fe-Z*	*Z*	*Fe-Z*	*Z*	*Fe-Z*	*Z*
0	30	30	16	16	–	–		–	–	–
10	20	28	13	15	12	–	100	–	10	–
20	10	28	13	14	06	–	20	–	06	–
30	07	25	11	14	02	–	10	100	08	–
40	02	23	10	13	02	–	07	93	06	100
50	0	20	10	12	01	100	06	88	03	91
60	0	23	07	10	01	96	06	83	02	85
90	0	23	04	10	0	92	04	78	02	76
120	0	25	02	08	0	90	03	77	01	72

(–) = Uncountable.

3.4. Removal of organic and inorganic contaminants

As depicted in Fig. 5, the order of adsorption of metals and anions with respect to adsorption per gram (mg g^{-1}) of Fe-Z is as follows: As (22.25) > Pb (17.56) > Cr (16.96); NO_3^{1-} (24.93) > PO_4^{3-} (13.40) > F^{1-} (10.38) with in 30 min. Similarly, the degradation order of Fe-Z for organic contaminants is DOP > CM > RD. Earlier studies conducted on modified zeolites had shown much less adsorption capacities for As (0.68–1.55 mg g^{-1}) [48,53], Pb (0.29–0.43 mmol g^{-1}) [11,54], Cr (3–4.36) [55,56] and fluoride (0.09–2.31 mg g^{-1}) [57,58]. On the other hand, high adsorption capacities were reported for surfactant modified zeolite for nitrate (24 mmol kg^{-1}) [59] and phosphate (75.8–79.4 mg g^{-1}) [60].

Considering the case of organic contaminants which also have the endocrine disrupting abilities, Fe-Z is able to degrade almost 100% DOP as compared to the CM and RD owing to its simple structure as compared to the other two. Much less phthalate removal potential had been observed by simple zeolite in previous studies 24.7–33.8% [61] which was enhanced to 100% by use of ozonation/UV assisted degradation [62].

3.5. Mechanistic explanation for removal of multiple contaminants

Zeolite is known for its different properties that make it a material of choice for water filtration assemblies [63]. Among these properties, their capability to exchange ions is of utmost importance. Modification to the basic structure of zeolite also aids in achieving the high adsorption capacity and removing multiple nature contaminants [10,64]. Earlier reported studies (Table 1) have also shown the increase in adsorption capacities towards different contaminants by modification of the zeolite. The inclusion of Fe into the porous structure of zeolite enhances the available surface area and hence allows multicomponents to get adsorbed on to the surface and/or absorb into the pores. The uptake of cations is mainly attributed to combined effect of ion exchange and adsorption [65]. In case of anions, the usual phenomenon that takes place is occlusion and adsorption. Further the iron doped into the zeolite can result in surface modification leading to formation of positively charged oxihydroxide which facilitate binding of anions onto zeolite [64]. For the removal of organic contaminants and microbes, the initial removal occurs based on adsorption on the surface and porous structure of zeolite which later on are degraded by Fe present in the zeolite. In case of antimicrobial activity, iron nanoparticles probably attach to the membrane of microbes and damage it by disrupting resulting in halting the cell activity. These nanoparticles interact with different types of microbes to different extents and hence resulting in bactericidal and bacteriostatic activities that vary with contact time [66].

3.6 Treatment of drinking water samples

In order to determine the effectiveness of the Fe-doped catalyst, real drinking water samples collected from different areas and suburbs of Lahore city were treated and checked for the CFU value before and after treatment with Fe-Z, other physio-chemical parameters were also accessed. The results hence are represented in Fig. 6. It can be clearly seen that Fe-Z is not only able to effectively reduce the CFU value of the water but in addition to that it also helps in reduction of total hardness, conductivity and pH of the samples.

3.7. Future aspects of current research

The current research is based on simple modification of self-prepared nano-zeolite by doping it with iron nanoparticles and use of this nanomaterial for multi-contaminant treatment of drinking water. The results are encouraging and showed high removal capacity for inorganic (both cationic and anionic), organic and microbial contamination from drinking water. The material can be effectively used for the preparation of filtration membranes by development of inter-linkages between the polymer matrix and the nanocomposite

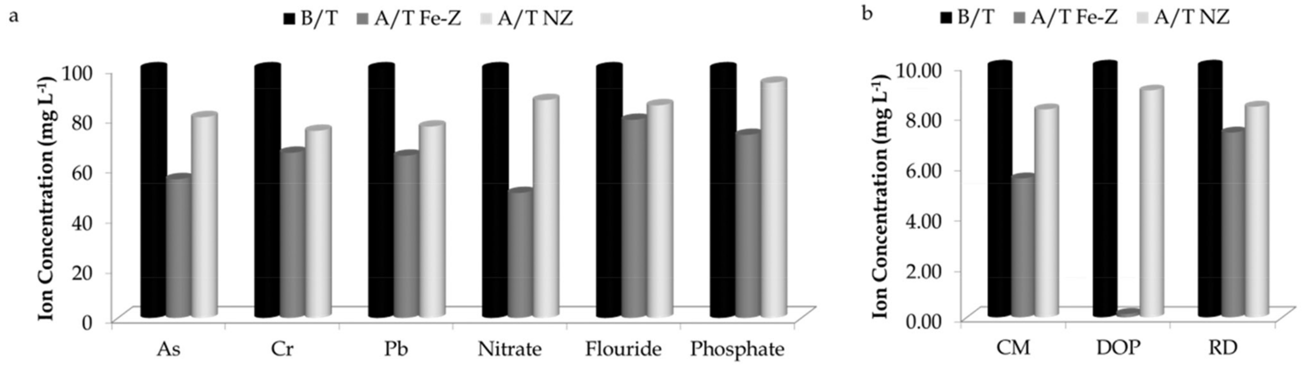

Fig. 5. Adsorption potential and catalytic degradation potential of Fe-Z and NZ against a) inorganic and b) organic contaminants of Fe-Z.

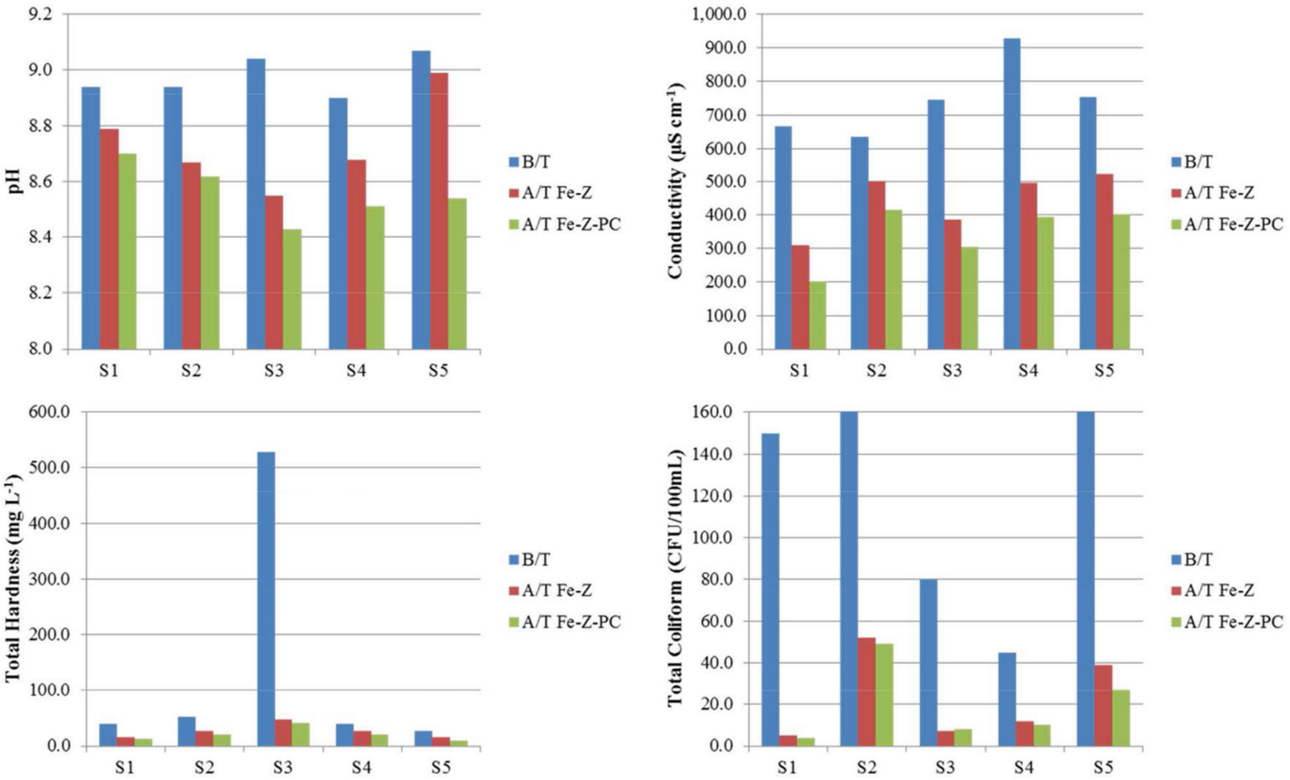

Fig. 6. Physio-chemical and biological parameters of drinking water samples as determined before and after treatment with Fe-doped zeolite and Fe-doped zeolite clay disc.

making it applicable in various setups for easy and one-step purification of water available to general public especially in rural areas.

4. Conclusion

Nano-composite material, i.e., iron-doped zeolite, for treatment of drinking water for processing for a) biological purification, b) inorganic and c) organic pollutants' decontamination was prepared by simple chemical approach. The prepared material offers advantages by removing the three diverse kinds of contaminants in one step without the need to using different treatment methods and chemicals for drinking water purification hence saving the excessive cost incurring. The filter material can also be used for neutralization and/or softening of water. The nano-filter material contains the ceramic support embedded with iron doped zeolite as the potential active material which was characterized using FT-IR, SEM/EDX and XRD. The material was compacted into a disc using pottery clay as a support for its better and effective utilization in filtration units. Treatment of simulated water samples (contaminated with common water-borne pathogens, i.e., *S. typhi, B. subtilus, E. coli, S. aures* and *P. aeruginosa*) and actual tap water samples with iron-doped zeolite showed effective de-contamination of the samples within 30 min. Real tap water analysis also suggested the considerable decrease in pH, conductivity and total hardness of the samples indicating the multi-purpose nature of the material prepared.

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