



The removal of iron from synthetic water by the applications of plants leaf biosorbents



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ABSTRACT

The toxic metals present in drinking water pose a threat to the human health. The huge populations are effected to poisonous metals mainly by the water uses. Iron is a heavy metal and found in the earth crust. The presence of iron in water might be recognized to the mixing of rocks and minerals, acid mine drainage, landfill leachate or industries waste discharges. Excessive iron ingestion can lead to an illness known as hemochromatosis. This can be the reason for liver, heart failure as well as diabetes and vomiting and skin aging etc, so that it is necessary to remove iron from water. Bio-sorption is eco-friendly method for treatment of waste water. These methods have certain advantages such as lower cost, easily available and reused. The plant leaf biosorbents have different biosorption capacities, which varied within each taxonomic group and depend on their physical and/or chemical pre-treatment as well as the operational conditions. In these research work, six locally available plant leaf biosorbents i.e. neem leaf, jayapalm leaf, guava leaf, sapota leaf, custard apple leaf and mango leaf biosorbents are uses. The mango leaf and guava leaf biosorbents show that the best performance for iron removal from water. Then the optimizations are done in the various parameters like pH, contact time, biosorbent dosages, temperature and rotation speed over mango leaf biosorbents for further improvement in their performances for iron adsorption. This procedure can be made cost-effective by regenerating and reapplication of plant leaf biosorbents after removing the iron from water.

1. Introduction

Iron is a chemical element with symbol Fe (from Latin: ferrum). In its metallic position, iron is exceptional in the earth's crust, partial to deposition by meteorites. Iron ores, by distinction are amongst the major abundant in the earth's crust, even though extracting utilizable metal from kilns or furnaces. The presence of iron in water may be ascribed to the mixture of rocks and minerals, acid mine drainage, landfill leachate, sewage or industries wastes. In normally iron exists in ferric state. The presence of iron at concentrations above 0.1 mg/L can cause harm to gills of fish. Free radicals generated on outside of gills will be the main reason for oxidation of tissue and leads to huge damage of gill tissue and anemia (Batchelor and Dennis, 1987). The body of a grown human contains about 4g (0.005%) of iron, mostly in haemoglobin and myoglobin. Iron can present in two forms, soluble Ferrous iron (II) and insoluble Ferric iron (III). At the pH conditions in drinking water supply ferrous sulphate settle out as corrosion colored silt, those water tastes unpleasant in stain laundry and plumbing fixtures. Iron occur in mixed forms as the individual ions (Fe^{2+}) or in undissolved higher forms mostly

as $Fe(OH)_3$. They can be exists in colloidal shape (bound to humic matter). Iron is the next most abundant metal present on the earth (Korngold 1973). The major common resource of iron in groundwater is by the disintegration of iron present rocks. Industrial waste, rusting or corrosion of water supply pipes and reservoirs causes contamination of water by iron (Ho et al., 2000a). The acceptable limit set by BIS (Bureau of Indian Standards) for iron present in drinking water is 0.3 mg/L, when increase this limit in municipal water supplies it cause turbidity, poor taste and odor, staining of laundry and plumbing (Devi and Ravindranath, 2012). In humans, if the iron is present in excess it causes stomach upset, ulcers, mental retardation, liver and brain damage. The more concentration of iron present in water can be the reason for injure the skin cells and raising the speed of skin aging. The more concentration of iron ingestion can lead to an illness called hemochromatosis. This can be the reason for liver failure, pancreatic and heart injure as well as diabetes (Kumari and Ravindranath, 2012). When consumed with food, stomach indigestion is normally shown, mainly to nausea and vomiting etc. So that, it is necessary to remove iron from polluted water and bring it down in its permitted limits. Iron supplements can decrease

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the effects of certain medications, including those for treating [restless legs syndrome](#) and thyroid problems (Rao et al., 2012). [Reflux disease medications](#) can reduce the amount of iron that the body absorbs from food and supplements. The permissible limit set for total iron present in the most adults range from 8 mg to 27 mg. Iron scarcity chlorosis is an important nutritional disorder for crops rising in calcareous soils and causes declines in the vegetative growth as well as marked yield and value losses (Ravulapalli and Ravindhranath, 2017).

Heavy metal ions in the ecosystem have a serious impact on all living organisms if exposed for a long period of time because they are toxic, cumulative and uncompostable. There are some methods to remove the presence of heavy metals chemically such as chemical precipitation, solvent extraction, coagulation, complexion, ion exchange, membrane separation and adsorption (Darmokoesoemo et al., 2016a). The adsorption method is one of the most effective method for decrease the concentration of heavy metals in the water. The silica gel, mangrove crab shell, mud crab, horn snail, algae and bagasse-bentonite are highly capable for removal of heavy metals from the water. Adsorption technique chosen with the advantage, that the costs involved were relatively low and does not cause toxicity (Kuncoro et al., 2018a). Horn snail shell powder contained chitin (19–28%) and calcium carbonate (65–70%) that potentially used as heavy metal adsorbent in wastewater that cheap and effective (Darmokoesoemo et al., 2016b). The usage of wastes bagasse would be admirable from environmental and solid waste management point of view. Adsorption of heavy metals by adsorbent from mixture of bagasse-bentonite follows pseudo second order model with correlation coefficient value of 99.99% (Kuncoro et al., 2018b). This study focuses on the investigation of adsorptive behavior of heavy metals by adsorbents in single metal system, bi-metal system and tri-metal system (Kuncoro et al., 2018c). Bio-sorption can be identified as the ability of organic resources to collect heavy metals from wastewater although metabolically mediated or physico-chemical pathways of uptake algae, bacteria, fungi and yeasts have showed to be potential metal bio-sorbents (Naat et al., 2021). Biosorption is a physical and chemical procedure by which individual material becomes attracted to another. The mechanism of biosorption is a complex procedure those involves the binding of sorbate onto the biosorbents (Kheraa et al., 2020). The various materials can be applied as biosorbents those participate the binding of metal ions by physical (electrostatic interface or van Der Waals forces) or chemical (displacement of either bound metal cations (ion substitute or protons) binding, reduction, precipitation and complexation (Balaji et al., 2014).

Biosorbents have the chemical groups like amine, amide, sulfonate, carbonyl, sulphydryl, carboxyl and phenolic groups that can attract and requisition metal ions. A property of bio-sorbent depends upon the nature and structure (living/non-living) (Baharudin et al., 2018). Identification of bio-sorbents for the procedure of bio-sorption is a most important challenge. The developments of bio-sorbents with the ability to join/uptake metal ions with more affinities (Neolaka et al., 2018c). A broad type of bio-materials exist in environment can be applied as bio-sorbents for the removal of metals from polluted water resources (Ho et al., 2000b). The various type of plant, animal and microbial biomass and their derivatives; plant, manufacturing and irrigation wastes; and by the pollutants yielded from different industries can be applied as bio-sorbents. It is necessary to choose a bio-sorbent from the huge range of present resources (Benaisa et al., 2016). The certain properties of a best bio-sorbent are more empathy for metals (biosorption ability), low economical cost, accessibility in more amount and simple desorption of the adsorbed metal ions and potential many recycle of the bio-sorbent (Indracanti and Gunturu, 2019). Biosorption ability of the biosorbent can be definite as the concentration of biosorbate (metal ions) biosorbed per unit weight of the biosorbents (Deepika and Pradeep Kumar, 2016). A huge range of biological materials residue, mainly plant leaf biosorbents have usual high consideration for toxic metal removal and recovery due to their better activity, economical in nature and huge amount available. The plant leaf biosorbents broadly used for

Table 1
Removal of iron by using various bio-sorbents.

Bio-adsorbent	Results and Analysis	References
Coconut Coir	The highest removal of 96% observed at 1hr contact time and at pH 5.0	Balaji et al. (2014)
Banana Peels	The percentage of iron removal by using banana peels is between 82% and 90%.	Baharudin et al. (2018)
Creeping Launae leaf	Optimum pH = 2.5 adsorption was dependent on contact time, pH, ion concentration and dosage. The removal percentage is more than 85%	Indracanti and Gunturu, 2019
Rice Husk	The 97.69% removal at pH 6	Deepika and Pradeep Kumar, 2016
Sorghum brewing waste	The brewing waste showed at removal of 93% while acid pre-treated brewing waste indicated 98% removal.	Akinpelu et al. (2019)
Sugarcane Bagasse	The highest removal percentages 93% was observed at 1hr contact time and pH = 5.	Saravanan et al. (2022)
Brown algae	The optimum removal of iron ions was obtained at pH 3, adsorbent dosage of 5 g/L and equilibrium time of 120 min.	Benaisa et al. (2016)

iron removal were showed, mostly focusing on their cellular arrangement, biosorption activity, their pre-treatment and modification, recycle, modeling of biosorption (isotherm and kinetic models), the progress of novel biosorbents, their valuation and probable use in the future (Akinpelu et al., 2019). The pre-treatment and changes of biosorbents main object to progress their biosorption capacity was applied and measured. Molecular biotechnology is an important part to explain the mechanisms at molecular level and to make engineered organisms with more biosorption ability and selectivity for the certain metal ions (Neolaka et al., 2020a,b).

Biosorbent performance for metallic ions is parts of chemical composition in the microbial cells of those are present. Mechanisms liable for biosorption, even though understand to a certain amount, might be one or mixture of ion exchange, complexation, coordination, adsorption, electrostatic interface, chelation and micro-precipitation (Eberhardt and Min, 2008). The pH condition is one of the important factors that influence the adsorption process of metal ions in the solvent. This is because the varying pH value influences the H⁺ ion charge and the interaction with iron metal adsorbent (Karthikeyan and Elango, 2007). According to this, the electrostatic interaction between nitrogen atoms and Fe²⁺ species present in the solution is weaker and also due to the interaction or competition between OH⁻ ions and Fe(II) anions (Neolaka et al., 2021a). When pH adsorption reaches at 6, it can be seen that adsorption capacity of biosorbents is higher than the adsorption capacity of other pH (Neolaka et al., 2021b). This phenomenon shows that the reverse conditions as compared to the ability of adsorption capacity at other pH change point. Fe²⁺ species change at pH 6 is compared at low pH condition and characteristic difference with recognition site can decrease IIP adsorption affinity toward Fe³⁺ species (Dey et al., 2021). The reusability value, which is relatively high and stable ($R = \pm 72.16\%$) based on the reusability test results, indicates that mango leaves has the potential to be applied on a larger scale (Kuncoro et al., 2018b). According to Balaji et al. Groundwater is mainly contaminated by anthropogenic activities like agricultural, domestic and industrial. In this study Coconut coir (COC) from agricultural waste have been selected as solid phase for removal of total iron. These materials showed remarkable binding characteristics for removal of total iron. The highest percentage removal of total iron was observed at Coconut coir (96%) (Balaji et al., 2014). In Baharudinet. et al., the measurement of concentration of iron and determining the effectiveness of iron removal by using natural biosorbent which is banana peels. The range of iron removal percentage is between 82.25% and 90.84% (Baharudin et al., 2018). According to Indracanti et al. various batch experiments were conducted on iron contained aqueous solution to find

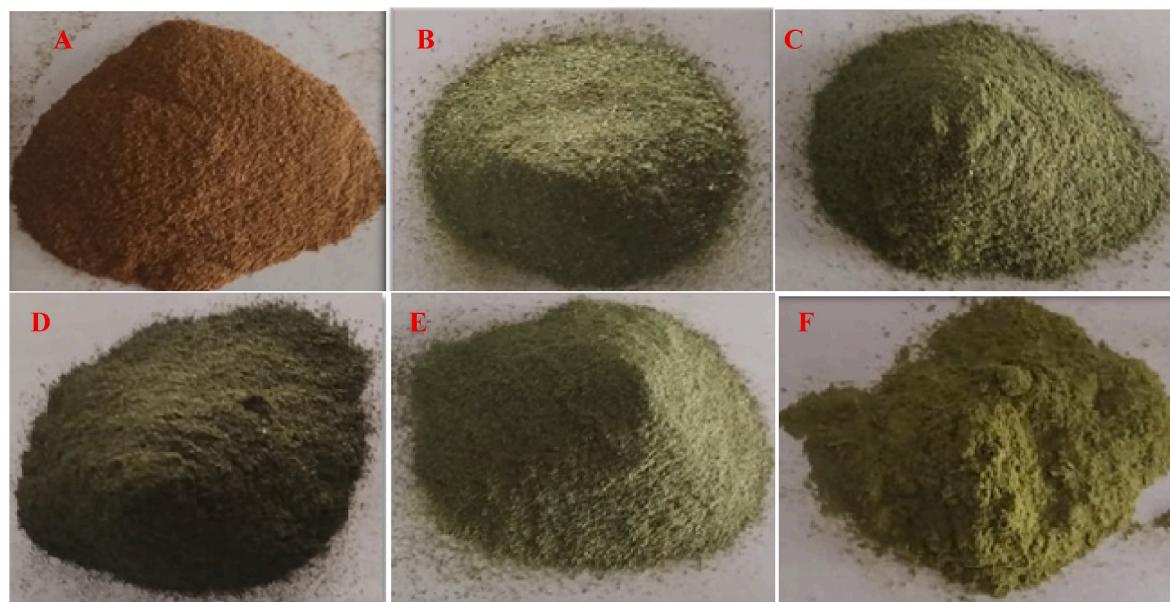


Fig. 1. Plant leaf biosorbents prepared in the laboratory (A) Mango leaf biosorbents, (B) Custard apple leaf biosorbents (C) Java plum leaf biosorbents, (D) Neem leaf biosorbents, (E) Sapodilla leaf biosorbents and (F) Guava leaf biosorbent.

out the removal of iron from aqueous solution. The percentage of iron adsorbed from solution increased with an increase in temperature. The removal efficiency varies with different conditions but it's above 85% (Indracanti and Gunturu, 2019). In Table 1 discussed about the removal of iron from water by using various biosorbents.

In Deepika et al. the efficient and low cost water purification systems are being utilized and being tried to be accessed worldwide for purification of water. Among all the low cost biosorbents materials was used, the ash produced from rice husk was proved to be show the best result in removal of iron and also available in local area having the cheaper cost. Highest efficiency 97.69% obtained at pH 6 (Deepika and Pradeep Kumar, 2016). According to Akinpeluet. et al., the concentration of iron present in the water samples from Mooi and Vaal rivers is more than required water standards by South African water regulation. In this study, brewing waste was used as biosorbent for the removal of iron. The brewing waste showed a removal percentage of 93% with residual iron concentration of 2.6 mg/L while the acid pre-treated brewing waste indicated 98% removal and 0.6 mg/L residual iron concentration (Akinpelu et al., 2019). In Muthuramanet. et al., the agricultural, domestic, industrial and anthropogenic activities are the main contaminants of groundwater. In this studies Sugarcane Bagasse from agricultural waste have been selected as solid phase extractor for removal of total iron. The highest percentage removal of total iron was observed at Sugarcane Bagasse (93%) (Saravanan et al., 2022). According to Benaisae et al. the metal ions presence in water is a serious environmental problem. Sargassum Vulgare is used as biosorbent material in this study for removal of iron from water sample. Batch adsorption experiments were carried out to evaluate the effect of process parameter such as pH, contact time and adsorbent dosage on the measurement of removal capacity. The optimum removal of iron ions was obtained at pH 3, adsorbent dosage of 5 g/L and equilibrium time of 120 min (Benaisa et al., 2016).

A huge concentration of materials residue has been study as biosorbents for the removal of iron extensively. The first main challenge for biosorption study was to choose the most potential types of biomass from a highly large area of readily available and low cost biomaterials. The biological materials residuals can combine the toxic metals contaminates; only those with more metal-binding capacity and selectivity for iron metals are appropriate for the application in a full-scale biosorption procedures. In this research investigation applying the neam

leaf, javapalm leaf, guava leaf, sapota leaf, custard apple leaf and mango leaf biosorbents. The mango leaf is complete of vitamins, enzymes, antioxidants and various additional raw materials (Viswanathan and Meenakshi, 2010). The active element of 'mangiferin' exist in this leaf has huge benefits. The mango leaf containing water or drink in residual type to the zone off a various types of health problems. Guava leaf contains more concentration of vitamin C and decoction of guava leaf is extremely supportive in the relieving cough and cold as it helps acquire rid of mucus. Guava leaf also clarifies the respiratory tract, throat and lungs. Guava leaf as raw (GL) and activated Guava leaf (AGL) has been study for biosorption of metal ions from the water mixtures. Both biosorbent materials have been characterized by various physicochemical methods. The adsorption kinetics were measured and modeled by the rate and diffusion (Bag et al., 1998). The plant leaf biosorbents powder were characterized with respect to textural surface area, morphology and surface useful groups and material was applied as an biosorbent in a batch procedures to remove the toxic metals from water solutions in the conditions of various concentrations, pH, rotation period and temperature. A huge number of plant leaf biosorbents has been studied for their metal binding capacities in different favorable conditions (Cui et al., 2015). The huge efforts have been made to improve the biosorption procedures, including control the biomaterials, progress of rejuvenation and reuse, optimization of biosorption procedures etc. The procedure of biosorption is beneficial due to its reversible, does not need nutrients, a single-stage procedure of fast range has no more toxic effects and cellular development confirm the intermediates equilibrium concentration of metal ions and not controlled by the metabolism (Grote and Kettrup, 1985). The biosorption processes is a complex procedures those participate the binding of adsorbate onto the biosorbent. The mixed property of different parameters like biosorbent amount, pH, temperature, contact time, rotation speed and effect the production of novel types of metal as a result of biosorption. From the biosorption isotherms show how the sorbate molecules are dispersed in the liquid phase and solid phase when the system reaches equilibrium conditions. In current scenario, biosorption procedures have been participate as novel, cheap, capable and eco-friendly method for the removal of toxic metals from contaminated wastewaters produced from different manufacturing industries (Mahmoud et al., 2012).



Fig. 2. Process of addition plant leaf biosorbents in iron contaminated water (A) Shaking for mixing of biosorbents with iron polluted water (B) Filtration of biosorbents (C) Measuring the iron present in water by colour testing and (D) Comparing the removal percentages of iron by colour chart. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

2. Experimental

2.1. Plant leaf biosorbents preparations

Preparation of plant leaf biosorbent is an easy procedure which can remove iron from contaminated water to avoid the water pollution. After collecting the plant leaf biosorbent they are cleaned with distilled water and washed with diluted H_2SO_4 acid solutions then dried continue until the moisture gets evaporated. The dried plant leaf biosorbents are grinded by electric grinder into the fine powdered particles so, that we can find out how much amount of biosorbents required to remove iron from water. All the six biosorbents were tested on iron removal in water and find out the capability of each bio adsorbent in the removal of iron from water (Peez-Corona et al., 1998).

All the plant leaf biosorbents powdered are shown in Fig. 1. The collected plant leaf biosorbent materials were cleaned with distill water with several times to remove all the impurity present in the biosorbents. The cleaning procedure was repetitive until the colour of cleaning water was purely clean. Each biosorbent has different physical, chemicals and biological property for iron adsorption from water. The dried up biosorbent material was placed in a plastic bottle for biosorption study. In the biosorption procedures also verify the stability of used biosorbents (Park and Kim 2005).

2.2. Chemicals used

Sulfuric acid (H_2SO_4) Sigma Aldrich purity 97%
 Iron (III) Nitrate $Fe(NO_3)_3 \cdot 9H_2O$ Sigma Aldrich purity 99%
 Iron (II) Acetate $Fe(CO_2CH_3)_2$ Sigma Aldrich purity 99%
 Potassium Ferrate (K_2FeO_4) Sigma Aldrich purity 98.5%
 Iron (II) Hexaquo ion $[Fe(H_2O)_6]^{2+}$ Sigma Aldrich purity 98.5%

2.3. Procedure for determination of iron in water

Take 5 ml of water sample in the test tube. Insert 5 drops of iron reagent-1 (fe1) and 1 drop of iron reagent-2 (fe2). Mix and include 5 drops of iron reagent-3 (fe3). Combine the contents and stay for 2–3 min the colour to be shown. The colours that form was compared with iron colour chart and confirmation the iron present. The iron nitrates chemical was mixed in distilled water 10g per 1 lit of water. This sample was tested for iron by using iron test solutions. All samples were taken in conical flask as 100 ml. The biosorbent powder was added to iron containing water in 100 ml of water sample; this sample was kept on horizontal shaker for 1hr. This treated water sample was filtered with whattman filter paper. Then the samples were checked by iron indicating table to ensure that the sample is free from the iron contaminations.

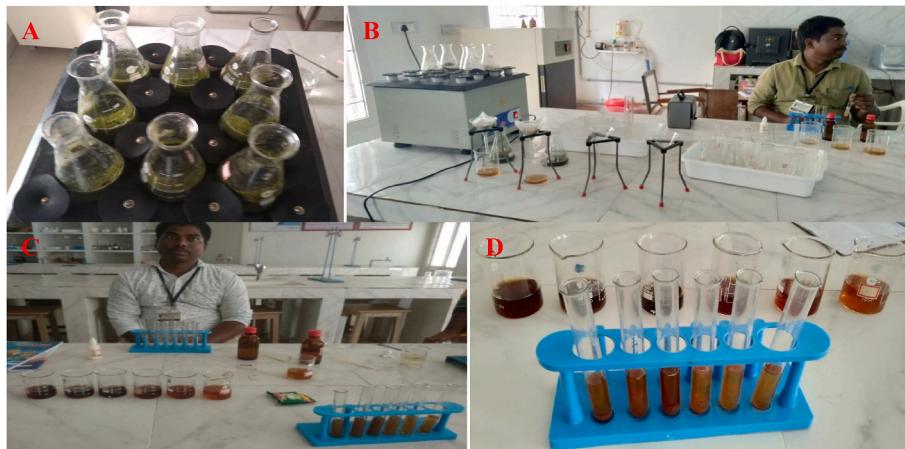


Fig. 3. Testing for removal of iron from contaminated water by applying plant leaf biosorbents (A) Mixing of iron polluted water with biosorbents, (B) Filtration of biosorbents in contaminated water (C) Analysis the iron present in water by colour testing and (D) Comparing the removal of iron from water by using plant leaf biosorbents. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

2.4. Procedure of addition biosorbents in water

Taken 1 L of water sample and added 1 mg/Liter of iron nitrate and separated into five equivalent parts of 100 ml solutions. Every sample added the biosorbent in the amount of 1g, 2g, 3g, 4g and 5g. The five samples are placed on flat rotator shaker for 2hr and afterward all samples are filtered up to the sample solution is free from the biosorbent particles. Then the same tests are made for find out the iron present in the water sample and after treatment evaluate the value with concentration of iron present initial than the addition of biosorbents, thus we get the removal proportion of iron.

After the identification of removal proportion of iron will be measured by analyzing the optimization i.e. different temperature, revolution speed, pH and will get out the contact on removal percentages. The plant leaf biosorbents which are capacities of controlling more loads of iron ions are most suitable for adding in the metal species. The process of addition various biosorbents in iron containing water samples, their filtration and colour testing to find out their concentration is shown in Fig. 2 (Tian et al., 2010).

2.5. Measuring the iron present in water

When iron concentration is measured in water samples based on the water sample colour. The colour of water sample is compared by the iron colour chart then the concentration of iron present in water was measured. The early iron concentration and removal percentage is measured thus the water samples are considered based on the colour. The comparisons of all plant leaf biosorbents for removal of iron from polluted water is shown in Fig. 3. The iron atom in the composite is combined to its intermediate neighbors by a coordinate covalent bond by accepting a single pairs of electrons from the non metal atom. By increase in the pH value of iron content if any presented in water will be removed or decreased in the sample (Sinha and Walker, 1972). The increase in dosage will also affect the pH value of water. The relatively high capacity of biosorbent to the adsorption's of iron as differences in bio-solids properties and potential impacts of temperature on the iron intakes. Agitation (action), putting into motion by shaking or stirring, often to achieve mixing. It means where by the combination of phases can be able and by which mass and heat transport can be improved in the phases or with surfaces. The increase in rotation speed improves the biosorption capacity of biosorbent by reducing its mass transport resistance. Contact time is the time that the biosorbents needs to stay wet on the surface in order to ensure their efficiency (Sinha and Walker, 1972).

By testing the sample at every half an hour time based on the removal percentage of iron in contamination water sample the contact time was calculated and bio-sorbent will settle down after the removing of iron contamination. The increases in time the speed of biosorption declines due to rise in percentage dispersion by metal ions present in the water samples. The analysis data was also measured in provisions of biosorption kinetics by applying the pseudo-first order, pseudo-second order and intra particle kinetic models. Batch analyses were done for different parameters, viz., pH, biosorbent dosage, contact time, initial metal ion concentration, rotation speed and temperature (Yavuz et al., 2006).

2.6. Determination the removal percentage of iron after biosorption procedures

The percentage removal of iron was measured by using the following equation:

$$\text{Removal (\%)} = \frac{C_i - C_f}{C_i} \times 100 \quad (1)$$

where.

Table 2

Particle size of various plant leaf biosorbents.

Biosorbents	Particle size (μm)	Biosorbents	Particle size (μm)
Mango leaf	1.18	Custard Apple leaf	4.78
Java Plum leaf	2.14	Neem leaf	5.46
Sapota leaf	3.68	Guava leaf	5.62

C_i = Initial iron concentrations (mg L^{-1})

C_f = Final iron concentrations (mg L^{-1})

V = Volume of the iron containing water solutions (mL)

W = Mass of biosorbent (gm)

2.7. Characterization

The X-ray diffraction (XRD) measurement of plant leaf biosorbents was done by using the Rigaku D/MAX-2400 diffractometer with Cu-K α emission at 40 mA and 40 kV. The standard crystallite size (d) of the plant leaf biosorbent was analysis by applying the Scherrer Equation. Fourier transform infrared spectroscopy (FTIR) analysis was measured by the Shimadzu 8400 FTIR spectrometer in the series of 400–4000 cm^{-1} and wavelength vary of (700 nm–25 μm). The scanning electron microscope (SEM) images of biosorbents samples were measured on Zeiss EVO 18 (SEM) instruments. It produced the more-resolution images of biosorbents by an electron beam. The Brunauer Emmett Teller Analysis (BET) was calculated by micromeritics ASAP 2020 instruments at the temperature of liquid nitrogen (-196°C) with a pressure vary of 0.05–0.30 P/P₀. The Brunauer Emmett Teller Analysis (BET) given information about the surface area, pore volume and pore size of the biosorbents.

3. Biosorbents characterization

Characterization of each plant leaf biosorbents prepared by various plants in the same conditions was analyzed by the following process and activity of biosorbents for iron removal was study below.

3.1. Morphological analysis of plant leaf biosorbents

Scanning Electron Micrographs (SEM) instrument was applied for the structural investigation of various plant leaf biosorbents. All the plant leaf biosorbents synthesized in the same conditions. The SEM micrograph shows that the massive changes in microstructure and textures of various biosorbents produced by different raw materials. The size range of each coarse residual particles was varied between (1.18–5.62 μm) measured by "Image J software" with different amount of agglomeration as mentioned in Table 2. Various heterogeneous convolutions also showed on the textural region (Tsezos et al., 1988). The changes in microstructure and texture of the different plant leaf biosorbents are represent in Fig. 4. As scene in SEM micrograph, the plant leaf biosorbents materials residual particles were the combination of more coarse, coarse, lower coarse, fine, partially fine and finest sizes produced by applying the Guava leaf, Neem leaf, Custard apple leaf, Sapota leaf, Java Plum leaf and Mango leaf biosorbents respectively. The particle size of various biosorbents in the increasing order was as follows: Mango leaf < Java Plum leaf < Sapota leaf < Custard Apple leaf < Neem leaf < Guava leaf biosorbents. From SEM investigation, confirmed that the homogeneity and texture of plant leaf biosorbents particles (Volesky and Naja, 2005).

The lower size residual particles present in mango leaf biosorbents has best capacity for iron adsorptions on their surface areas. The character and property of mango leaf biosorbents residual particles have also been modified with the varying of different mixtures present on the biosorbents. The surface has breaks and cracks as well as rough and different textural morphology with a better porous formation in the different sizes. Due to the presence of these opening, the biosorbents will

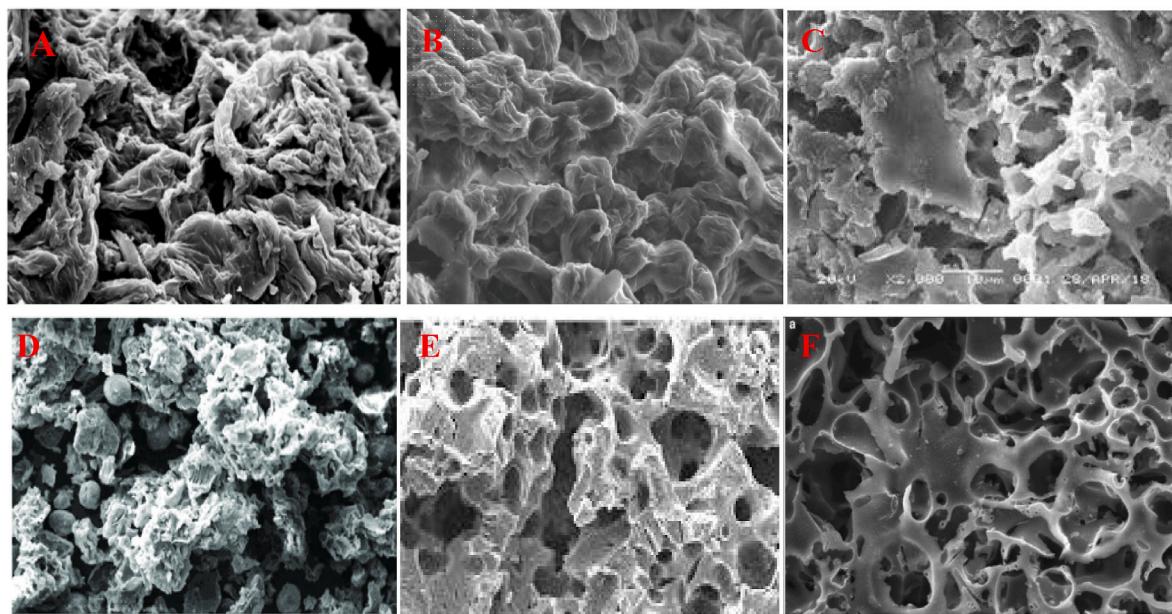


Fig. 4. SEM images of (A) Neem leaf biosorbents, (B) Javapalm leaf biosorbents, (C) Guava leaf biosorbents, (D) Mango leaf biosorbents, (E) Sapota leaf biosorbents and (F) Custard leaf biosorbents.

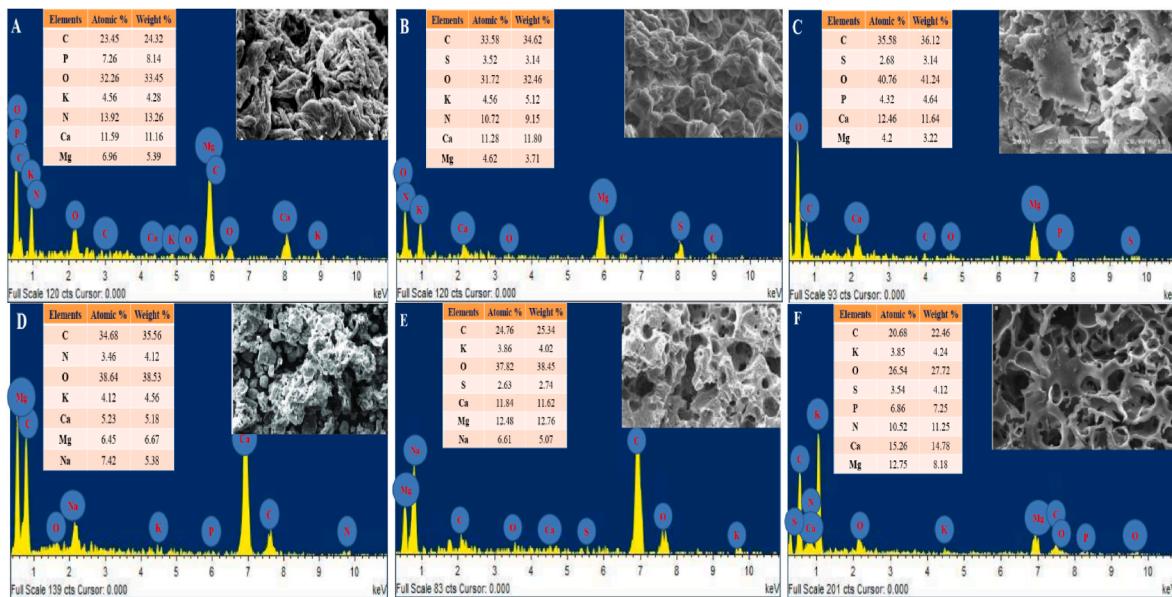


Fig. 5. SEM images of (A) Neem leaf biosorbents, (B) Javapalm leaf biosorbents, (C) Guava leaf biosorbents, (D) Mango leaf biosorbents, (E) Sapota leaf biosorbents and (F) Custard leaf biosorbents.

have a more ability for iron molecules as they can disperse into these opening pores and get attract on the active sites (Xu et al., 2010).

Two different procedures used in the synthesis of raw biomass were followed. The initial one was to monitor the residual particle size of biomass in a specific series by sieving. The next one is to remove and utilize the residual fine particles of lower than a particular higher in size value. From SEM investigation shows that the similarity and textural of purely clean mango leaf biosorbent particles residues (Biswas et al., 2007). After adsorptions of iron over mango leaf biosorbents the size of various residual particles present was nearly same to the fresh mango leaf biosorbents. After the acid modification, the texture of biosorbent became additional porous and variety produced due to the cracks opening by the acid treatment process. The biosorption there was obviously smoothening away of the biosorbent texture as iron ions are

adsorbed onto. An amorphous phase was detected on the plant leaf biosorbents (Nakamura et al., 1992).

3.2. SEM-EDX analysis of plant leaf biosorbents

The various elements are present in the plant leaf biosorbents surfaces was measured by the SEM-EDX techniques then calculated in huge scanning range by random for the samples of Guava leaf, Neem leaf, Custard apple leaf, Sapota leaf, Java Plum leaf and Mango leaf biosorbents. The study of SEM-EDX analysis has confirmed that all biosorbents were pure due to the presence of their related elemental peaks only. The elemental percentage division of the plant leaf biosorbents was analyzed by the application of IS 300 software. The SEM-EDX study performed on different sectional area of plant leaf biosorbents as

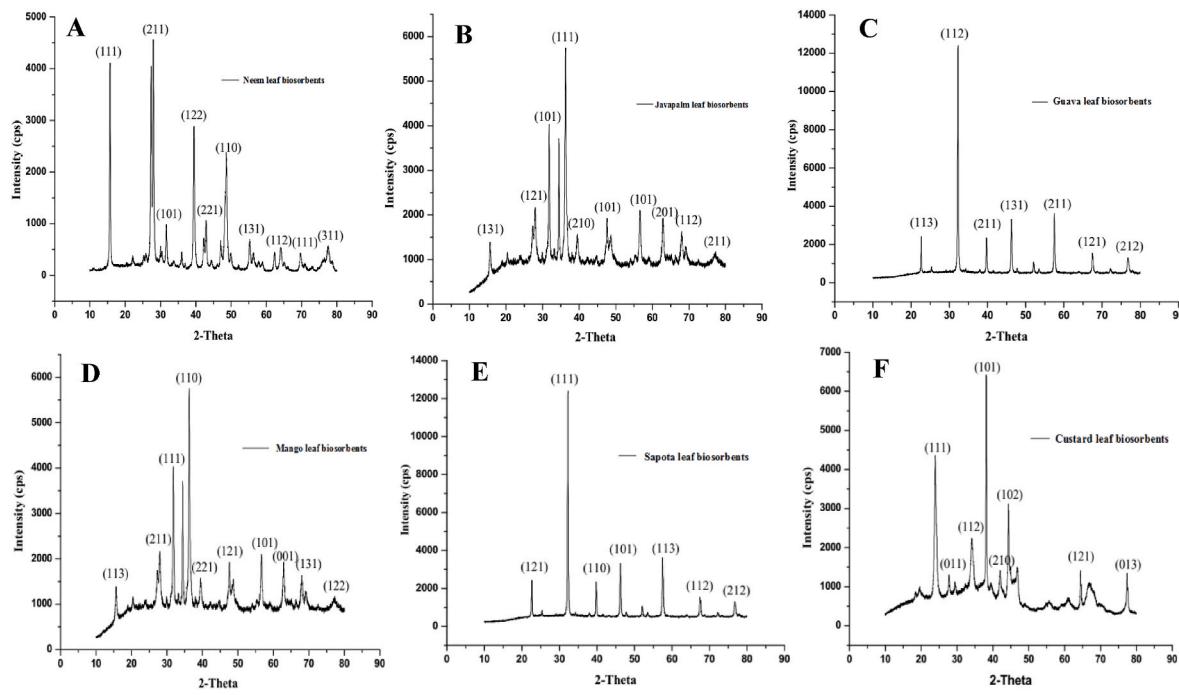


Fig. 6. XRD images of (a) Neem leaf biosorbents, (b) Javapalm leaf biosorbents, (c) Guava leaf biosorbents, (d) Mango leaf biosorbents, (e) Sapota leaf biosorbents and (f) Custard leaf biosorbents.

represents in Fig. 5 to getting the amount of various elements located at the various areas on the coarse surfaces. In the neem leaf biosorbents shows that the presence of C, P, O, K, N, Ca and Mg elements are 23.45, 7.26, 32.26, 4.56, 13.92, 11.59 and 6.96 respectively. The C, O, N and Ca elements at the more amounts is present in the neem leaf biosorbents (Kuncoro et al., 2018a). In the Javapalm leaf biosorbents represents that the presence of C, S, O, K, N, Ca and Mg elements are 33.58, 3.52, 31.72, 4.56, 10.72, 11.28 and 4.62 respectively. The C, O, N and Ca elements are more amounts and originating in the Javapalm leaf biosorbents. In the guava leaf biosorbents shows that the presence of C, S, O, P, Ca and Mg elements are 35.58, 2.68, 40.76, 4.32, 12.46 and 4.2 respectively. The C, O and Ca elements are more concentration found in the guava leaf biosorbents. In the mango leaf biosorbents shows that the presence of C, N, O, K, Ca, Mg and Na elements are 34.68, 3.46, 38.46, 4.12, 5.23, 6.45 and 7.42 respectively. The C and O elements are more concentration present in the mango leaf biosorbents. In sapota leaf biosorbents shows that the presence of C, K, O, S, Ca, Mg and Na elements are 24.76, 3.86, 37.82, 2.63, 11.84, 12.48 and 6.61 respectively. The C, O, Ca and Mg elements are more concentration present in the sapota leaf biosorbents (Neolaka et al., 2018a) (see Fig. 6).

In the custard apple leaf biosorbents shows that the presence of C, K, O, S, P, N, Ca and Mg elements are 20.68, 3.85, 26.54, 3.54, 6.86, 10.52, 15.26 and 12.75 respectively. The C, O, N, Ca and Mg elements are more concentration present in the custard apple leaf biosorbents. The presences of more oxygen in the mango leaf biosorbent those can create higher amount of active sites. So that it represents that the most excellent plant leaf biosorbent for iron adsorption from the water. The spent mango leaf biosorbents have the lowest concentration of oxygen as compared to the pure form (Luo et al., 2010). In the plant leaf biosorbents the opening are produced due to the evaporation of activating agent in the higher temperature carbonization. The SEM-EDX analysis is highly significant in the present conditions where the fractionalization of biosorbents is a normally done. The chemical adjustment even though the declining whole textural area of biosorbent can be really increases the biosorption capacity due to adjustments in the major groups, influences on the water solution chemistry and progress of intrinsic affinity of biosorbent due to the changes (Dey et al., 2021). The regular

Table 3
XRD analysis of the various plant leaf biosorbents.

Biosorbents	Structure	Crystallite size	Biosorbents	Structure	Crystallite size
Guava leaf	End-centered cubic	8.68 nm	Sapota leaf	Face-centered cubic	6.08 nm
Neem leaf	Face-centered cubic	7.26 nm	Java Plum leaf	Face-centered cubic	5.84 nm
Custard Apple leaf	Face-centered cubic	6.42 nm	Mango leaf	Face-centered cubic	4.16 nm

separation of micronutrient ions was scene on the SEM micrographs. The structures of textural plane were also observed. The macro-structure of biosorbent residual particles could be clearly observed from the images and textural changes instantly confirmed. The real adsorbent had a diversified, coarse and more opening textures mixture of different fibrous bonds and elastic formations (Frisoni et al., 2001).

3.3. Phase recognition and cell size of plant leaf biosorbents

The phase recognition and cell size of plant leaf biosorbents synthesized in the laboratory are analysis by the XRD procedures. The XRD analysis results discussed in Table 3 and provide important information about the texture, phase, crystal movement, lattice parameters, crystallite size, strain and crystal defects etc. XRD analysis of the Neem leaf biosorbent diffraction represents a wide peak at 2θ was 28.42, those are related (111), (211), (101), (122), (221), (110), (131), (112), (111) and (311) with the Face-centered cubic structures. The organic groups represented that the lignin and fiber may be the promising for the chemical compounds due to they are signification mixtures of neem leaf biosorbents (Neolaka et al., 2018b). The crystallite size of neem leaf biosorbent was 7.26 nm. In XRD diffraction pattern of the Javapalm leaf biosorbents shows that the crystalline part of material, while the amorphous part of fibers involve broader peaks. It represents a wide

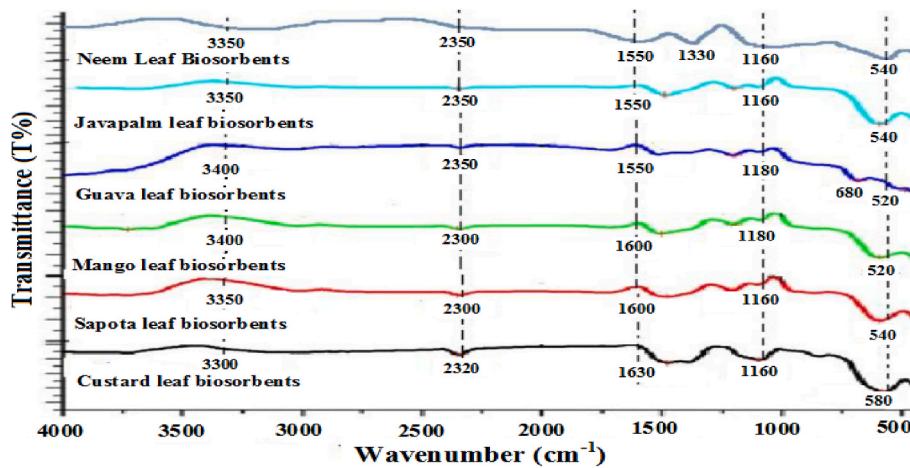
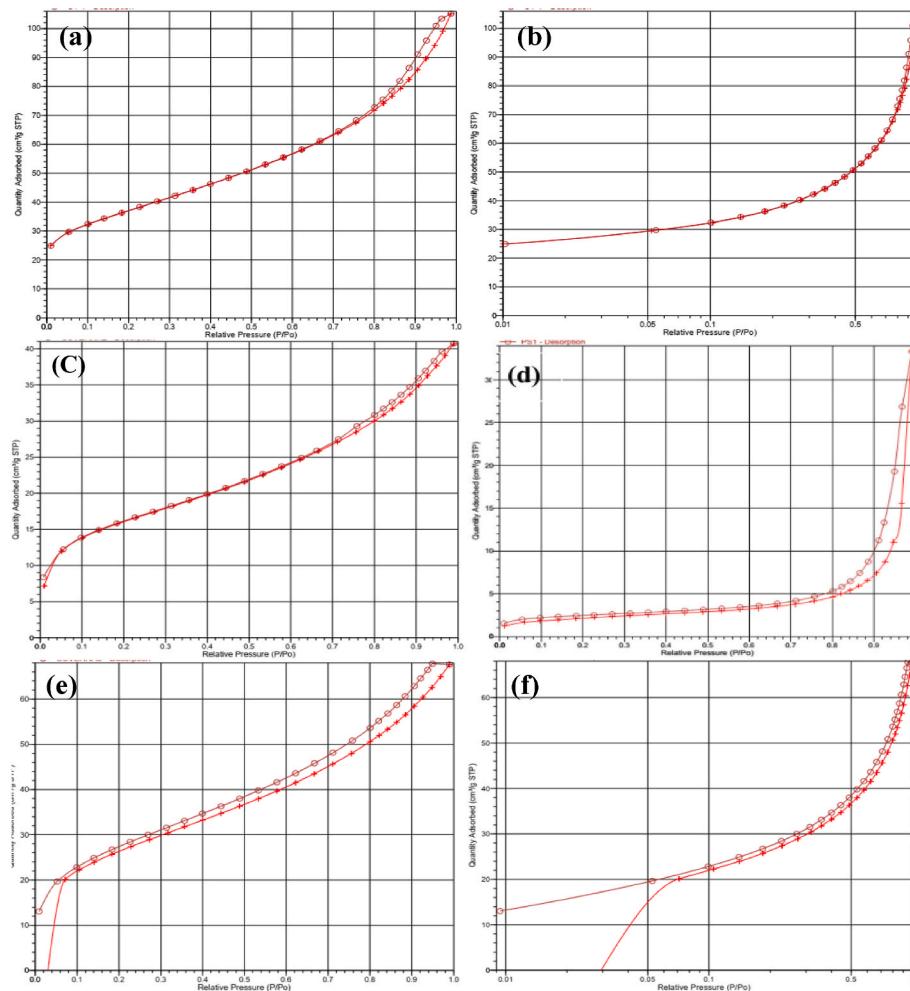


Fig. 7. FTIR analysis of the plant leaf biosorbents.

peak at 20 was 37.45, those was related (131), (121), (101), (111), (210), (101), (201), (112) and (211) with the Face-centered cubic structures. The crystallite size of Japapalm leaf biosorbent was 5.84 nm. In the mango leaf biosorbents diffraction peak at 20 = 32.85° and 35.65° to its lattice plane (113), (211), (111), (110), (221), (121), (101), (001), (131) and (122) Face centered cubic and crystallite size of mango leaf biosorbents was 4.16 nm.

The crystalline index of raw mango leaf biosorbent was 53%, and the result obtained for studied raw mango leaf was in accordance with their literature. Then, it is found that the diffraction patterns of fibers have low crystalline (amorphous). In sapota leaf biosorbents diffraction peak at 20 was 31.5° to its lattice plane (121), (111), (110), (101), (113), (112) and (212) Face centered cubic and crystallite size was 6.08 nm. After XRD study confirmed that the residual particles present in mango

Fig. 8. N₂ adsorption-desorption curves of (A) Neem leaf biosorbents, (B) Japapalm leaf biosorbents, (C) Guava leaf biosorbents, (D) Mango leaf biosorbents, (E) Sapota leaf biosorbents and (F) Custard apple leaf biosorbents.

leaf and Java Plum leaf are highly crystalline in nature. Thus raw and treated neem leaf and guava leaf biosorbents have good adsorptive characteristics for iron removal from water. In custard apple leaf biosorbents diffraction peak at $2\theta = 24.52^\circ$ and 38.65° to its lattice plane (111), (011), (112), (101), (210), (102), (121) and (013) Face centered cubic and crystallite size of custard apple leaf biosorbents was 6.42 nm (Luo et al., 2010).

After XRD study confirmed that the crystallite size of mango leaf biosorbent has smaller than the other plant leaf biosorbents therefore its shows that the better results for iron adsorption from water. The crystallite size of residual particles exist in plant leaf biosorbents obtained was as following order: Guava leaf > Neem leaf > Custard Apple leaf > Sapota leaf > Java Plum leaf. > Mango leaf. The particles present in mango leaf biosorbents was mostly crystalline form and producing small size high-intensity diffraction lines as compared to other biosorbents. As observed from Fig. 6, the moderately lower peaks in the XRD diagram showed that the prepared nanoparticles have amorphous grains. The amorphous characteristic of raw mango leaf biosorbent is due to the high lignin content (amorphous compound) in its structure. Generally admits that the more lignin and hemicelluloses content (amorphous compounds) present in the lignocelluloses materials lower crystalline to the material (Ho and McKay, 1999).

3.4. Categorization of materials present in plant leaf biosorbents

The major functional elemental groups present in the plant leaf biosorbents were recognizing by the Fourier transform infrared spectroscopy analysis. The various peaks show that the different types of chemical groups are present in the plant leaf biosorbents. The FTIR investigation of plant leaf biosorbents containing different absorption peaks as represents in Fig. 7. The peak at the $3,350\text{ cm}^{-1}$ and $3,400\text{ cm}^{-1}$ are major caused by the functional group of alcohols and phenols those have O-H stretch and H-bonded respectively. Peak $2,350\text{ cm}^{-1}$ and ($1,600\text{ cm}^{-1}$ and $1,550\text{ cm}^{-1}$) represents that the presence of alkanes with C-H stretch and alkynes with $-C\equiv C-$ stretch. At $1,330\text{ cm}^{-1}$ represents that the higher useful group of carbonyls. At $1,160\text{ cm}^{-1}$ and $1,180\text{ cm}^{-1}$ represents that the major groups of amines and aromatics group respectively. The absorption at 680 cm^{-1} corresponding to $-CO-$ functional group, along with the presence of (540 cm^{-1} and 520 cm^{-1}) shows the C-O bonds become weak.

To verify the presence of major functional groups those are capable to adsorb iron by FTIR analysis was studied. After the carbonization and active procedures the position and concentration of various peaks being distorted. These major groups facilitate to associate and trap the iron molecules. In additional, the band of 580 cm^{-1} shows that the presence of $C=C$ of aromatic rings. The FTIR data corresponding to the proximate study and observes the functional groups of biosorbents (Aksu, 2001). Each biosorbents represents that the mixtures of useful group like carbonyl and hydroxyl group in the biosorbents. Hydroxyls are alcohols group and have more ability towards iron biosorption. The pollutants phases are present declined in the following order: Guava leaf > Neem leaf > Custard Apple leaf > Sapota leaf > Java Plum leaf. > Mango leaf. Thus the mango leaf biosorbent has represents that the more purity as compared to other plant leaf biosorbents (Dey et al., 2019).

3.5. Textural regions analysis of plant leaf biosorbents

The textural region of every plant leaf biosorbents were prepared into the laboratory followed by drying into the oven was measured by the BET procedure. The isotherm curves of various biosorbents representing that the hysteresis loops of those desorption branch attached the adsorption curve with relative pressure 0.7 was showed in Fig. 8. The biosorbents hysteresis loop represents that the pores were geometries of mesopores. The mesopores geometries of prepared biosorbents show H1 hysteresis loops. The pore opening size distributions (PSDs) as analyzed by the Barrett-Joyner-Halendar (BJH) technique from the desorption

Table 4
Textural property of the various plant leaf biosorbents.

Biosorbents	Surface Area (m^2/g)	Pore Volume (cm^3/g)	Ave. Pore Size (Å)
Guava leaf	10.68	0.254	50.34
Neem leaf	14.35	0.316	45.62
Custard apple leaf	22.28	0.368	40.63
Sapota leaf	27.24	0.408	34.87
Java plum leaf	35.58	0.478	28.64
Mango leaf	43.24	0.512	23.46

branch of nitrogen isotherms. The presence of hysteresis loop at a relative pressure (P/P_0) of 0.8–1.0 represents that the porosity creating from the non-crystalline intra-aggregate residue open voids and pore spaces produced by the inter-particle connection. In Fig. 8 represents that the N_2 adsorption-desorption isotherms curves of various surface area distributions of guava leaf, neem leaf, custard apple leaf, sapota leaf, java plum leaf and mango leaf biosorbents respectively. The surface areas of guava leaf, neem leaf, custard apple leaf, sapota leaf, java plum leaf and mango leaf biosorbents were 10.68, 14.35, 22.28, 27.24, 35.58 and $43.24\text{ m}^2/\text{g}$ respectively (Babarinde et al., 2009). The isotherm curve shows important information on the mesopores structure by its hysteresis loop in Table 4.

The major surface area and total pore volume are two major factors those can influence the plant leaf biosorbents capacity for iron removal. The pore volume of guava, neem, custard apple, sapota, java plum and mango leaf biosorbents were 0.254, 0.316, 0.368, 0.408, 0.478 and $0.512\text{ cm}^3/\text{g}$ respectively. The surface area and pore opening of fresh mango leaf biosorbents were much higher than the other biosorbents. A higher amount of more pores opening are present in the mango leaf biosorbents means a massive concentration of iron molecules are adsorbed on their surfaces, so that, it has to represents that the most excellent activities (Vimala and Das, 2009).

The reaction between iron and plant leaf biosorbents, the concentration of pores present in the biosorbent surfaces was blocked so that the surface area of used plant leaf biosorbent was declined. The biosorbent surface has breaks and crevices as well as non-uniform and different morphology with a best developed porous configuration in different sizes. Due to the presence of this cavity, the biosorbent will have a more ability for iron molecules biosorption as they can disperse into these opening and get trapped on the active sites (Pavan et al., 2006). In nucleated crystals are usually good due to their more textural region. A biosorption procedure is the surface phenomena participates the addition of solute from liquid to the solid texture; those are mainly influenced by the ability of biosorbents and contract chemically. Finally, the good performance of mango leaf biosorbents in iron containing water make them promising candidate for removing of pollutants (O'Connell et al., 2008).

4. Iron removal from contaminated water

The results those are getting after the analysis carried out for removal of iron in the various conditions. It showed that the biosorbent was completely active for removing iron from water in normal conditions. After the preparation of biosorbent apply these biosorbent for iron removal from water. Rust iron is collected from corroded materials. This powder is added to distilled water 0.1g per 1,000 ml of water. This sample was tested for iron by using iron test solution. This sample was again taken in conical flask as 100 ml. The naturally occurred iron-rich materials and waste materials shown in Fig. 9, such as cheap iron ore, steel slags, red mud, ferric sludge, ferric water treatment residuals, iron oxides, iron-rich humus soils, iron oxide tailings, iron rich calcareous soils and goethite. The colour of water sample was checked with iron indicating table to ensure that the sample is free from iron. The filter sample was tested for iron using iron test solutions (Lesmana et al.,



Fig. 9. Rust iron contaminated water samples.

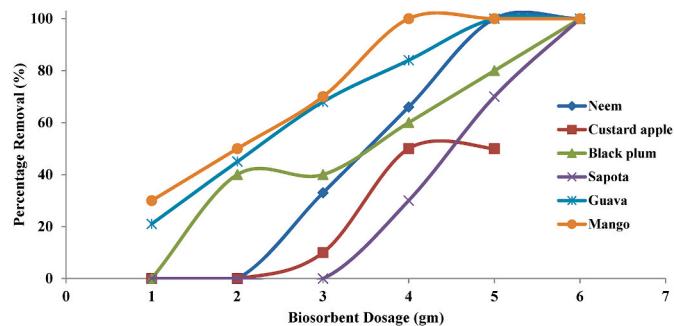


Fig. 10. Comparison graph of different biosorbents in the removal of iron from water.

2009).

For iron concentration measurement in water take 10 ml of water sample was filled into the clean square sample cell. The reagent residue pillow was added to the sample cell. The water mixture was swirled to mix. An orange colour was produced if iron exists in the water sample. The water solution was waited for 3 min reaction. After identification of removal percentage followed by conducting the optimization i.e. different temperature, rotation rate and pH then we will observe the effect on removal percentages (Araújo et al., 2007).

4.1. Comparison of iron removal from water by applying various biosorbents

This is the comparison between all types of bio-adsorbent as shown in Fig. 10, i.e. easily understand which bio-adsorbent removed the iron; this comparison graph is drawn based on all the results. Neem leaf bio-sorbent has no effect on the removal of iron content at the dosage of 2.5g. It started showing the effect after increasing the dosage beyond 2.5g and at 3g the removal efficiency has a value of 33.33%. At 3.5g and 4g the value was 70%. The maximum removal efficiency which was 100% achieved at 4.5g and value was retained at 5g as well. Java Plum leaf acts as a good quality bio-sorbent material and has shown good results in iron removal among the other materials have tested. There is no removal up to 1g of dosage, and with increase in dosage beyond 1g, the effect started. At 2g and 3g the efficiency value was 40% and at 4g, 5g, 6g of dosage the efficiency gradually increases i.e., 60, 80, 100 respectively. Sapodilla leaf bio-sorbent has slow pickup at the beginning. It requires more dosage to show its effect. It has zero efficiency up to 3g of dosage. It starts working from 3g dosage, at 4g the efficiency was 30%, at 5g is 70% and at 6g of dosage 100% removal efficiency was observed.

Mango leaf biosorbent initially showed results at low as 1g of dosage. The initial conditions of iron removal percent was 30% at 1g, 2g the value was 50%, at 3g of dosage it's 70% and 4g, 5g and 6g the maximum removal efficiency was obtained which was 100%. Mango leaf biosorbents showed that the best performance and immediate results. The removal efficiency is directly proportional to the dosage. In

Table 5

Comparison of various plant leaf bio-adsorbent for iron removal from water.

Bio-sorbent Dosage (g)	Neem (%)	Java Plum (%)	Guava (%)	Sapota (%)	Custard Apple (%)	Mango (%)
1	0	0	20	0	0	30
2	0	40	45	0	0	50
3	33.33	40	68.5	0	13	70
4	70	60	85	30	50	97
5	100	80	100	70	50	100
6	100	100	100	100	50	100

guava leaf biosorbents the 1g biosorbent removal percentage is 20%, at 2g is 45%, 3g of dosage is 68.5% removal efficiency, 83% removal was achieved at 4g and at 5g and 6g the completely removal of iron from water was obtained. Custard apple leaf bio-sorbent has no effect up to 2.5g dosage. After 2.5g the results slowly increases, at 3g dosage efficiency was 13%, at 3.5g the value is 20% and starting from 4g of dosage the removal mechanism stopped at 50% and same result was obtained at 4.5 and 5g of dosage. These biosorbents shows that the metal-sequestering property can be applied to remove the concentration of iron present in water solution from ppm to ppb level. The various methods for removing iron metal ions from water solutions mostly consist of physical, chemical and biological technologies. To controlling of the biosorbent into suitable residual particles can be made by applying various procedures like trap in a strong but permeable matrix in the membrane-like formation. The immobilization can decline the concentration of binding sites that are available to metal ions as a best part of the sites are fixed inside the bed (Ho et al., 2020).

From Table 5 confirmed that the mango leaf bio-adsorbent shows that the best performance for iron removal as compared to the other plant leaves bio-sorbents. Guava leaf biosorbents has gradual increase in iron removal with increase in dosage. Mango has good results with even at low bio-sorbent dosage. Only custard apple is failed to get 100% removal efficiency. Sapota requires more dosage to get results. These graph shows that the percentage of iron removal at different dosage of bio adsorbents. The mango leaf, guava leaf and neem leaf biosorbents shows that the best performance for iron removal from water. The order of percentage removal of iron for six different biosorbents was found as Mango leaf > Guava leaf ≈ Neem leaf > Java Plum leaf ≈ Sapota leaf > Custard Apple leaf. The 5g of mango leaf and guava leaf biosorbents show that the best performance for complete removal of iron from water. For mango leaf biosorbents further analysis were done on the variables like pH, contact time, amount of biosorbent, temperature and agitation speed. Biosorption is physiochemical procedures that affect physically in the certain biomass those permits concentrating inertly and binding pollutants onto its cellular structure (Erdem et al., 2004).

4.2. Optimization of mango leaf biosorbents for iron removal from water

After the screening of all six biosorbent, the removal percentage of iron is high in these three biosorbents i.e. neem leaf, guava leaf and

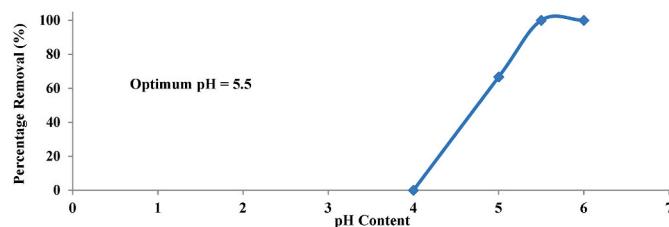


Fig. 11. Optimization of pH in iron removal from water.

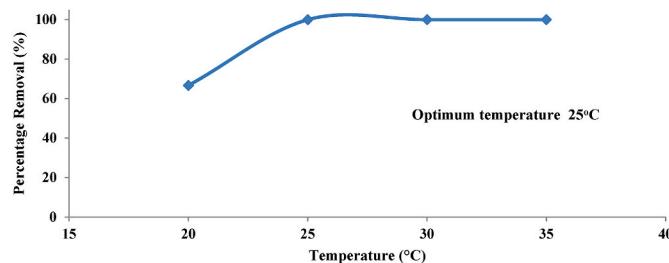


Fig. 12. Optimization of temperature in iron removal from water.

mango leaf biosorbents. The mango leaf and guava leaf biosorbents are shows that the best performance for complete removal of iron from water. Therefore it is necessary to shows that the most favorable concentration of biosorbents, optimum pH, temperature, time and agitation speed for removal of iron from water. Biosorption is affected by different processes parameters such as pH, temperature, early metal ion concentration, biosorbent dosage and agitation speed and contact time. The mixed biosorbents showed that the better adsorption properties towards the removal of iron from water mixtures.

4.2.1. Optimization in pH for iron removal from water

In adsorption procedures the hydrogen ion concentration was measured as individual of the most significant parameters that effects the biosorption property of metal ions in the water mixture. It influences the solubility of metal ions in the water mixture, substitutes several of the positive ions exist in the active sites and influences the amount of ionization of adsorbate in the reaction. Adjust the pH of water sample with iron contaminated and optimum dosage of mango leaf biosorbent at 6g by adding the acid or base i.e., NaOH and H₂SO₄.

The removal capability at various pH levels and obtain the most excellent results as the best pH value. At pH value 4 the removal efficiency was 0%, the pH 5 was 40% and at pH value 5.5 and 6 the complete removal of iron from water was achieved. The optimum pH value of mango leaf biosorbent for iron removal from water is 6.5. These results showed that the iron removal was increased up to 5.5 then declined at pH difference from 5.6 to 6. The removal percentages of iron with increase in pH as shown in Fig. 11 can be understand on the basis of decrease in resist in the proton and metal cations for certain useful groups and by decline in the positive surface charge, those fallout in a lesser electrostatic repulsion in the outer surface and metal ions.

4.2.2. Optimization in temperature for iron removal from water

Evaluation of thermodynamic parameters is an indispensable and major component of sorption processes studies. Thermodynamic studies do not just represent the nature of process; they provide information on whether the mechanism is predominately based on physical or the chemical nature of interactions. Although there are several theories and approaches for calculating thermodynamic parameters in a sorbate-sorbent system, the most accurate basis for such calculations is the usage of equilibrium constant. The biosorption of Fe(II) on the mango leaf biosorbent was studied at various temperatures in 60 min of contact time. The removal efficiency at 20 °C is lower as compare to higher

temperatures in the test i.e. 97% at 25 °C the complete removal was obtained at 30 °C. In Fig. 12 show that the optimum temperature for iron removal from water is 30 °C and further increasing the temperature it was make constant.

The increase in biosorption of Fe(II) with heat may be ascribed by the two factors. One is an increase in the amount of active sites presenting for biosorption on the biosorbent. The other is decrease in the thickness of boundary layer surrounding the mango leaf biosorbent with temperature and positive effect on the biomass transport struggle of Fe(II) in the border level. The kinetic behavior was described by the pseudo-second-order model for in cooperation of the metallic species (Gupta et al., 2011).

4.2.2.1. Adsorption mechanism of thermodynamic study for iron removal from water. The present sorption systems obey the Langmuir isotherm; the following reversible process can represents the heterogeneous equilibrium sorption of each sorbate. In the case of sorbents with a significant part of small pores in their structures, like in the case of a high amount of microspores, some pores may hardly be pervious for sorption of hydrated metallic ions. The pore diffusion may probably exert a role in the process, though the overall analysis shows that the Langmuir isotherm model is completely fitted with the experimental data. Evaluation of thermodynamic parameters is an indispensable and an important component of sorption processes studies. Thermodynamic studies do not just indicate the nature of the process; they give information on whether the mechanism is predominately based on physical or chemical nature of the interactions. Although there are several theories and approaches for measuring thermodynamic parameters in a sorbate-sorbent system, the most accurate basis for such calculations is usage of equilibrium constant (Lima et al., 2019).

$$\text{Sorbate(aq)} + \overline{\text{Sorbent}} = \text{Sorbate.Sorbent} \quad (2)$$

where Sorbate (aq) denotes to sorbate in the aqueous solution, Sorbent is the sorption site existing on the surface of sorbent and the bar means that the species are in the solid phase. The thermodynamic equilibrium constant (K_{eq}) for the above heterogeneous equilibrium can be given by the following relation:

$$K_{eq} = \frac{A_{\text{Sorbate.Sorbent},e}}{A_{\text{Sorbent},e} \times A_{\text{Sorbate},e}} \quad (3)$$

where $A_{\text{Sorbate.Sorbent},e}$ and $A_{\text{Sorbent},e}$ are the activity of occupied biosorption sites and the activity of vacant sorption sites at the equilibrium condition, respectively, and A_{Sorbate} is the equilibrium activity of sorbate in the solution phase. To apply the above equation as an equilibrium constant for calculating thermodynamic parameters, the activity coefficient of sorbent should be estimated from Langmuir law, or infinite dilute value of equilibrium constant (K_{0eq}) should be used, for which $\gamma \approx 1$. The high porosity even after the modification with the iron nanoparticles is a very crucial aspect regarding adsorption application, revealing that the presence of NPs did not lead to the blockage of the pores' entrances.

From the best-fitted model at the different temperatures, the equilibrium constant is obtained one for each isotherm at a given temperature. The adsorption is a heterogeneous equilibrium where the adsorbate is present in a fluidic phase (aqueous solution) and the adsorbent will be present in a solid phase. Usually, the concentration of solid phase [Adsorbent] and [Adsorbent-Adsorbate] is considered constant, because the number of moles of the solid phase divided by the volume of solid phase is practically constant, because the solid phases did not alter their volume during the process of the adsorption (Imamoglu and Tekir, 2008). The isotherms of adsorption at various temperatures, preferably using nonlinear fitting, and for the best isotherm model obtain the equilibrium constant (K isotherm). Then, this K isotherm should have their value converted from L mg⁻¹ into L mol⁻¹. Where the probability of occurrence the chemical bond of adsorbate with the solid surface of

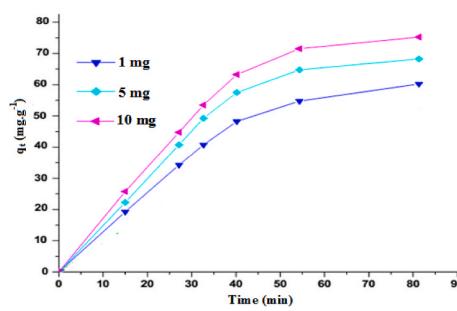


Fig. 13. Kinetics data of iron molecules adsorption over mango leaf biosorbents at certain pH, temperature and biosorbents dosage (Pseudo first order models fitted with them).

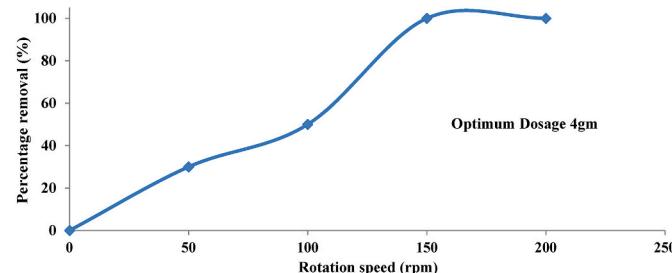


Fig. 14. Optimization of rotation speed in iron removal from water.

the adsorbent should be ruled out since the principal mechanism of adsorption depends on the chemical nature of the adsorbent and adsorbate (Kheraa et al., 2020).

The areal rate of a given biosorbents for iron adsorption was defined as the moles of Fe adsorbed per unit surface area of biosorbents per unit time. The activation energy (E) of the reaction can be evaluated from the slope of the plot $\ln(k)$ versus $1000(1/T)$ as per equations and plotted in Fig. 13. The rate constant, k , was a function of temperature and can be expressed by Pseudo-first order. The Arrhenius' equation gives the dependence of rate constant of a chemical reaction on the absolute temperature, a pre-exponential factor and other constants of the reaction (Bag et al., 1998) (see Fig. 14).

The correct way to calculate the equilibrium constant for adsorption system is to obtain isotherms of adsorption at different temperatures. In this case, hydrogen bonds, $\pi-\pi$ interactions, and other Van der Waals forces should take place. Therefore, all judgment about the process of adsorption should consider several factors, such as the chemical characteristics of the adsorbent and adsorbate, results of other analytical techniques to prove the mechanism of interaction (Rahmani-Sani et al., 2020). The data of iron sorbent over mango leaf biosorbents under the conditions, when the biosorbents exhibited steady performance, versus gmol/ml at different temperatures (Darmokoesoemo et al., 2016a). When a reaction has a rate constant that obeys Arrhenius' equation, a plot of $\ln(k)$ versus $1/T$ gives a straight line, whose gradient and intercept can be used to determine the pre-exponential factor. The pre-exponential factor value is positive which may be explained by more randomly organization of the studied metal ions at the solid/solution interface, and the liberation of hydration water molecules during the sorption phenomenon. The thermodynamic experiment represents that the adsorption processes involving both metals were exothermic (K_c and K_d) (Lima et al., 2019). For this purpose, after deriving the correct thermodynamic equilibrium constant from isothermal studies, considering the principles of chemical equilibrium, information was provided about the most propagated constants used as the thermodynamic equilibrium in the literature (Kuncoro et al., 2020b).

4.2.3. Optimization of rotation speed in the iron removal from water

The rotation speed of conical flask containing mango leaf biosorbents

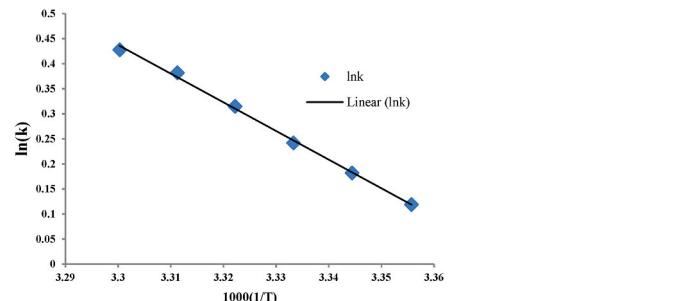


Fig. 15. Optimization of contact time in mango leaf biosorbents for iron removal from water.

with iron contaminated water is also very important factors affecting the iron removal from water. The samples were tested for iron removal efficiency to find out the optimum rotation speed. In this study observe that at which revolution speeds the iron having completely removal by the mango leaf bio-adsorbent. In rotation speed test the samples were placed into the conical flask and best amount of bio-sorbent is added into them, these conical flask were put into the rotary shaker and each flask was reevaluated at various speeds for 1hr time. The influences of contact time on the biosorption of iron on the mango leaf biosorbent were analyzed in the period from 120min by fixing the additional parameters such as biosorbent amount and temperature for every study. The rotation speed is varying from 0 to 200 rpm.

At optimum dosage of 5g mango leaf biosorbent at 50 rpm rotation speed the 30% iron was removed, 100 rpm rotation speed 50% iron was removed and 150 rpm rotation speed has 100% iron removal efficiency and further increasing the rotation speed it was making constant. The increase in agitation speed as shown in Fig. 15, it raises the biosorption capability of biosorbent by reducing its mass transport resistance. Although the additional turbulence improves the biosorption of iron ions, it might be also besides to the damage of physical nature of biosorbent. A changing speed represents that the more similarity for difference with an improved ability of biosorption. The increasing rate rotation speeds results in the presence of current fact those results in the failure of homogeneous nature of suspension. The high turbulence may also decline the period of contact among the biosorbate and biosorbent, thus reducing the degree of biosorption (Imamoglu and Tekir, 2008).

4.2.4. Optimization of contact time in the iron removal from water

The water samples containing optimum dosage of mango leaf biosorbent were kept in the rotary shaker for different time periods and were tested for the removal efficiency to get the most favorable contact period required for complete removal of iron metal. The iron contained mango leaf biosorbents water sample was rotated for half an hour which has no effect on the removal of iron content in the sample. Increasing the rotation speed it takes 1hr for complete removal of iron and result is same for 1hr 30min and 2 h. Thus need to achieve the maximum iron adsorption depend on the form of biosorbent, metal ion and their mixture. The speed of biosorption is slowing rate at the start in an hour

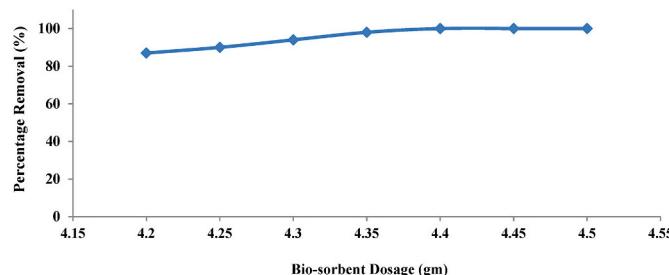


Fig. 16. Optimization of mango leaf biosorbent dosage in iron removal from water.

due to each active sites are not effective for metal ion biosorption. With the increases in time the speed of biosorption increases due to improve in the percentages of biosorptions to the iron metal ions. The contact time applied for highest uptake of iron ions by mango leaf biosorbent was dependent on the early metal ion concentration as shown in [Fig. 16](#). To confirm the accurate measurement was necessary, the whole sorption analyses were approved over 1h. The iron removal over mango leaf biosorbents was increased by the contact period ranges from 30 to 120min. These results show that the best contact period of 60 min for highest removal of iron from water.

This effect was significant due to certain period the highly crucial parameters for a lower cost wastewater treatment procedures. All curves had superior linearity (correlation coefficient) showing that the more binding of Fe(II) ions to the textural of mango leaf biosorbent residual particles. All the parameters such as dosage of biosorbent and pH of water solution were making constant. The iron metal removal was improved with an increase in the contact period before the stability was reached. The iron and mango leaf biosorbent contact time is a crucial parameter in the adsorption reactions ([Öztas et al., 2008](#)).

4.2.5. Optimization of mango leaf biosorbent dosage for iron removal from water

Biosorbents shows the binding sites for metal biosorption therefore its amount highly influenced the biosorption procedure. The raise of plant leaf biosorbent dosage at specified iron ion presence in water increases the biosorption of iron due to the higher textural region those in rotate increase the amount of existing binding sites. At lower amount of mango leaf biosorbent, the concentration of iron metal biosorbed per unit mass of the biosorbent was more. At the higher concentrations of mango leaf biosorbent the amount of iron biosorbed per unit mass was declines. This is due to the lesser adsorbent to binding sites ratio due to the insufficient amount of solute present for the total distribution onto the available binding sites and probable interface in the binding sites.

The amount of mango leaf biosorbent is major issue as the biosorption mostly depends upon the textural area of biosorbent existing for the interface of pollutant. For analyzing the influence of mango leaf biosorbent amount on the removal of Fe(II), the biosorbent amount is changed from 4.2 to 4.5g, fixing the other parameters in water solution

like pH, initial metal ion concentration and temperature. In optimum biosorbent dosage test as shown in [Fig. 17](#) take the various amounts of mango leaf bio-sorbent materials which are added optimum level in to the water and measured for removal of iron from contaminated water. At 4.35g of mango leaf biosorbent dosage the removal of iron from water was 97% achieved then increasing 4.4g of mango leaf biosorbent dosages the 100% iron removal from water observed. The increasing mango leaf biosorbent dosage increased the percentage removal of iron and additional increase in the biosorbent dosages did not major changes in the biosorption yield. This observation represents that the highest iron biosorption was reached after an optimum amount of mango leaf biosorbents i.e. 4.35g of mango leaves biosorbents added into the water. Therefore the concentration of iron ions bound to the biosorbent and concentration of free ions remains stable even with more addition of biosorbent dosages ([Neolaka et al., 2021b](#)).

4.3. Final optimization of mango leaf biosorbent for iron removal from water

Biosorption is a physical and chemical treatment processes have been applied for increasing their performances and for raising their biosorption ability. These modifications are highly significant in the performance of mango leaf biosorbent to removal of iron, being an applicable feature to better their application as a mango leaf biosorbent. Parameters from breakthrough curves were obtaining and values in the breakthrough point showed that the mango leaf biosorbent with the excellent results for iron removal. From [Table 6](#) observed that the best sorption was obtained at basic pH is 5.5, optimum dosage is 4.4g, optimum contact period is 60min, optimum temperature is 25 °C and optimum rotation speed is 150 rpm. The optimization process variables for adsorptive of iron metal from water was also reported. For different application require better technology with additional study to find out the best conditions those involve a longer period. To appreciate the contact effect those helps in optimizing the investigational parameters and give a consistent numerical model those has been widely used (see [Table 7](#)).

The major object of this investigate is to find out the best condition of mango leaf biosorbents procedures variables to get the highest iron removal effectiveness for its uses in the more-scale operation. The application of biosorption technology for purification of iron metal polluted waste waters has turn into different process to usual purifications due to the more selectivity, simply conduct, lesser operating expenditure and more effectiveness in removing mainly smaller

Table 6
Kinetics parameters and statistical indices of iron adsorption over biosorbents.

Kinetics model	C_0 (mg/L)	Kinetics Parameters K_a (min ⁻¹)	q_{cal} (mg/gm)	R^2 values
Pseudo-first order	1	0.12	32.46	0.9734
	5	0.16	44.62	0.9846
	10	0.21	61.74	0.9952

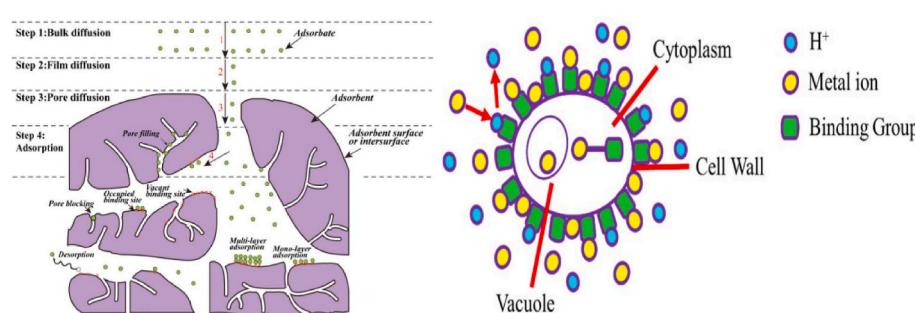


Fig. 17. Various steps involved in the biosorptions of iron from water.

Table 7

Maximum removal of iron from water at different pH, time and temperature by using mango leaf biosorbent.

Biosorbents	Maximum percentage of Removal (%)	Biosorbent Dosage (g)	pH	Time (min)	Temperature (°C)	Agitation Speed (rpm)	
Mango leaf	100%		4.4	5.5	60	25°C	150

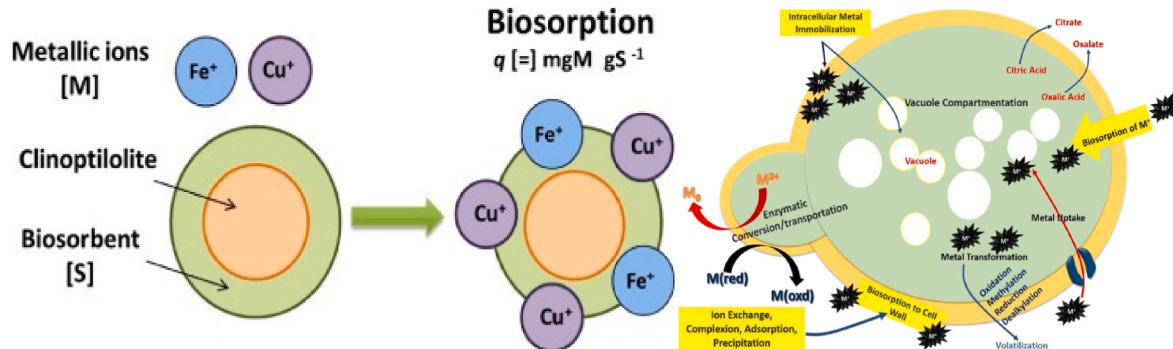


Fig. 18. Kinetics model of the iron biosorptions processes.

amounts of iron metals from the mixed solutions. The carbonyl and hydroxyl groups of poly phenols could be accountable for the biosorption characteristics of mango leaf biosorbents. The oxygen atoms of every carbonyl and hydroxyl group are measured as high Lewis base centers due to the presence of empty doublet electrons; those permit coordination by the electron poor metal ions. The increase in biosorbent dosages results in reduces of the interface duration to make the clear stability. The nature of adsorbent and its compactness affect the instance required to arrive the stability (Neolaka et al., 2020b).

5. Mechanism of iron removal from water by the biosorptions procedures

Adsorption is a physicochemical procedure that usually applies mass transport of a material (i.e. adsorbate) from gas or liquid phase to the surface and/or border of solid phase. The first bulk diffusion step is shown in Fig. 18 can be used to the water solution, due to the regular addition of the adsorbent and adsorbate in water mixture can reduces the contact of mass transport problems. The final step, i.e., physical/chemical process has been done rapidly; therefore the adsorption kinetic is mostly measured by the film dispersion and/or pore dispersion (Neolaka et al., 2018c). The layer dispersion rate is proportional to the liquid concentration and surface area of the biosorbent. Increasing the relative speed velocity among the fluid and particles, i.e., create the strong liquid layer on the surface area of particles thinner and speed the film dispersion rate (Neolaka et al., 2020a,b). The pore dispersion speed depends on the movement of contaminants in the pores, those are

associated to the pore formation and pore allocation of the adsorbents, the molecular size and types of the adsorbates, those have lower influenced by the liquid concentration or surface area of the biosorbent particles (Matis and Zouboulis, 2001). The surface area change of the mango leaf biosorbents can also be a major factor effecting the removal performances and needs to be characterized further. The pore dispersion rate is mainly associated to the square root of adsorption time ($t^{0.5}$). So that, if a linear correlation was get the adsorption rate and $t^{0.5}$, it can be showed that the pore dispersion procedures dominates adsorption at these period. The biosorptions procedures have been agreed in a batch type of reactor system (Ngurah Budiana et al., 2021). A steady reactor system may be applied for improved applications; those can be useful in the field conditions more efficiently. In the batch method, fixed concentration of mango leaf sorbent is combined with solutions containing a known amount of iron in containers for a certain contact time and therefore the adsorbate is divided by the sedimentation or filtration (Sheshmani and Mashhadri, 2018).

The increase in amount of mango leaf biosorbent dosages reduces the biosorption capacity due to increasing percentage of open binding sites. The decreasing of mango leaf biosorption capacity is the addition of particles may take place at more adsorbent concentration, those formations regarding the mango leaf iron biosorption procedures, those are necessary to represents that the biosorption rate and manage the residual time. To better applications realize the biosorption procedures, various numerical models have been projected to investigation the kinetic data from the batch adsorption studies (Bowell, 1994). In Fig. 19 shows that the better-fitting kinetic model, those can be used into the

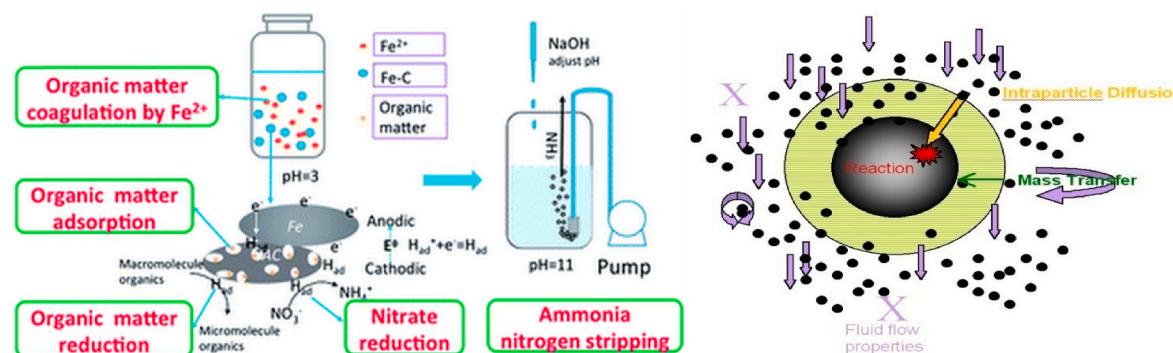


Fig. 19. Reaction mechanism of the iron adsorption over biosorbents.

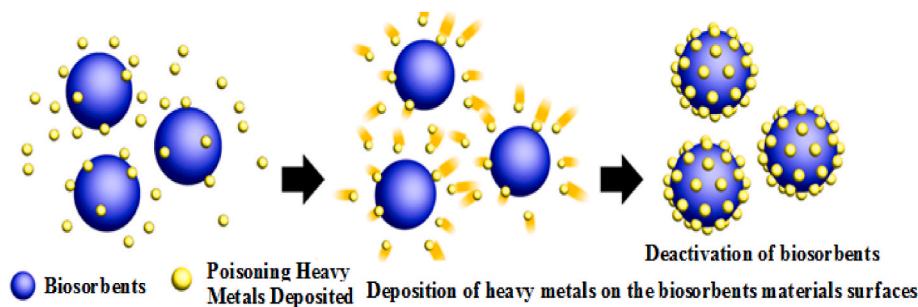


Fig. 20. Deposition of contaminant on the biosorbent surface areas.

adsorption reaction model and adsorption diffusion model. The iron oxides exist in the various types in nature, such as $\alpha\text{-Fe}_2\text{O}_3$, Fe_3O_4 , $\gamma\text{-Fe}_2\text{O}_3$, $\alpha\text{-FeOOH}$, $\gamma\text{-FeOOH}$ and HFO. Amongst which, hematite, magnetite and maghemite are more analyzed iron oxides in water purification as they hold more textural charge and redox movement characteristics, polymer-phase that applied temperature-induced phase change and distinctive magnetism (Parastar et al., 2021).

The magnetic characteristics of mango leaf biosorbents depend on the different parameters such as the mixing composition, size and area of the mango leaf biosorbents particles. The magnetization of iron oxides modify with the changing of particle sizes. It was also showed that the rod-like residues are a better applicant for increasing the magnetic partitioning compared to circular ones, due to their steady magnetic instant originating from shape anisotropy and affinity to create huge chaining residues (Aigbe et al., 2021). The surface area, porous structures, surface active sites and probable redox characteristics of iron oxides are major reasons for their development of biosorption activity (Neolaka et al., 2021c). The biosorbents residuals with lower size particles, especially in nanosizes, tend to contain a single set of physical and chemical characteristics that are various from their resultant bulkiness materials due to the quantum result. The functionalized biosorbent species, such as amino, imino, imidazole, thiol and carboxylic have been produced for more-efficient removal of iron metal oxides contaminants (Sheshmani et al., 2017). The mango leaf biosorbents species may be transformed from the huge solution onto the biosorbents during the intra-particle dispersion/transport procedures. The speed limited step was taken into concern and intra-particle dispersion model was applied. The edge layering biosorption phase was rapidly done; the intraparticle dispersion phase reflected iron adsorption onto the mango leaf biosorbent surfaces (Li et al., 2020). The major available sites reacted with iron by the mass transferring, followed by the similar reaction going on the slowly lower available sites measured by the dispersion. The intra-particle dispersion may be managed by the reaction of adsorption kinetics (Nidheesh et al., 2013). The iron biosorption ability increase with the increasing temperature; this is explained by the growing diffusion of Fe^{2+} into the micropores of biosorbents or the production of original energetic sites at the higher temperatures (Li et al., 2020). The unpleasant effect of ionic strength on iron uptake represents that the potential participation of ion replace mechanism. An enhancement of ionic strength can reduce the coulombic attraction in the positive and negative charge. Future studies shall be going to the iron removal from polluted water that will produced more effects into the influence of parallel anions (Siqueira et al., 2020).

In Fig. 20 the intraparticle diffusion may govern by the reaction of adsorption kinetics. The iron biosorption capacity increased with the increasing temperature; this is explained by the increasing penetration of ionic iron into micropores of biosorbents or the formation of new active sites at higher temperatures. The thermodynamic parameters such as ΔG° , ΔH° and ΔS° calculated using the following equations, are important parameters to evaluate the thermodynamic feasibility and nature of adsorption process. In the eqⁿ (4–7) discuss about the kinetics reactions mechanism of various biosorbents for removal of iron (Matis

and Zouboulis, 2001). In these equations, ΔG° , ΔH° and ΔS° are the free energy of sorption (kJ/mol), the standard enthalpy change (kJ/mol) and standard entropy change (J/(mol.K)), respectively; T (K) is the absolute temperature in Kelvin; R (8.314 J/(mol.K)) was the universal gas constant; K_d is the thermodynamic equilibrium constant; α is the adsorbent dose (g L^{-1}). The positive effect of enthalpy change shows that the endothermic nature of reaction, which was supported by increases in q_m as temperature increases. The ΔG° values decreased with the increasing reaction temperature, a result of the positive entropic contribution ($\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$) (Li et al., 2020).

$$\Delta G_o = -RT\ln K_d \quad (4)$$

$$\ln K_d = \Delta S_o R - \Delta H_o RT \quad (5)$$

$$K_d = \alpha q_e C_e \quad (6)$$

$$\Delta G_o = \Delta H_o - T\Delta S_o \quad (7)$$

The iron sorption to biosorbents modified materials might be the overall entropy changes reduce when the equilibrium state was attained, as species are adsorbed onto the biosorbent surface. The pH value is important in the adsorption, because it affects the species of iron ions and ionization of active functional groups on the biosorbent surfaces (Selatnia et al., 2004). The kinetic studies were helpful for predicting the adsorption rate with time and explaining the active interactions of iron ions with adsorbents which gave important information for designing and modeling the processes. The Thomas model was used to describe the performance of adsorption process in a fixed-bed column. This model assumed plug-flow behavior in the bed and used Langmuir isotherm for equilibrium and second-order reversible kinetic (Parastar et al., 2021). The decrease in adsorption with the rise of temperature may be due to the formation of the adsorbate– adsorbent complex which becomes unstable resulting in the escape from solid phase to the bulk solution. It is also likely that the instability of the complex may be accompanied by damage to the adsorption sites of the adsorbent thereby decreasing the metal ions uptake at higher temperature (Selatnia et al., 2004). As the temperature increases, the values of ΔG° become more negative for each metal. The negative and small values of free energy change ΔG° were an indication of the spontaneous nature of the adsorption process. The negative values of standard enthalpy change ΔH° for the intervals of temperatures were indicative of the exothermic nature of adsorption process (Frisoni et al., 2001).

5.1. Adsorption isotherms studies

The experimental data were fitted using Langmuir and Freundlich adsorption isotherms. The Langmuir isotherm equation is written as:

$$\frac{C_e}{q_e} = \frac{1}{q_{max} K_l} + \frac{C_e}{q_{max}} \quad (8)$$

where C_e is the equilibrium concentration of adsorbate (mg/lit) and q_e is the amount of metal adsorbed per gram of the adsorbent at equilibrium

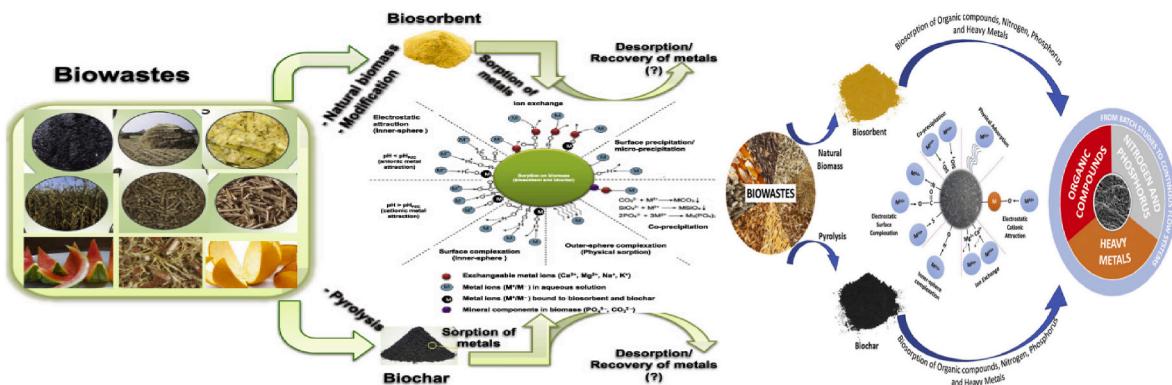


Fig. 21. Deactivation of various plant leaf biosorbent surfaces by iron adsorption processes.



Fig. 22. Regeneration of mango leaf biosorbents by using various treatments.

(mg/g). q_m (mg/g) and b (l/mg) are Langmuir constants related to adsorption capacity and rate of adsorption, respectively. The values of q_m and b were calculated from the slope and intercept of the Langmuir plot of C_e versus C_e/q_e . Freundlich isotherm describes an empirical relationship that exists between the adsorption of solute and surface of adsorbent. This isotherm could be effectively utilized to study the heterogeneity and surface energies. The empirical equation proposed by Freundlich is:

$$q = K_f C \frac{1}{n} \quad (9)$$

where, K_f and n are coefficients; q is the weight adsorbed per unit weight of adsorbent; C is the concentration of the metal solution. Taking logarithm and rearranging the equations. The constant K_f is an approximate indicator of adsorption capacity, while $1/n$ is a function of the strength of adsorption in the adsorption process. These constants can be evolved by line increasing the above equation by adopting mathematical techniques.

$$\log q = \log K_f + \frac{1}{n} \log C \quad (10)$$

If n is equal to 1 then the partition between the two phases is independent of the concentration. If the $1/n$ value is below 1 it indicates a normal adsorption. On the other hand if $1/n$ is above 1 it indicates cooperative adsorption. The pseudo-first order and pseudo-second order models have been tested on the experimental data at different contact time. The pseudo-first order model is expressed using this equation (Kumari and Ravindhranath, 2012).

$$\log (q_e - q) = \log q_e + \frac{K_d}{2.303} \times t \quad (11)$$

where q_e (mg/g) is the mass of metal adsorbed at any time t and k_1 (min^{-1}) is the equilibrium rate constant of pseudo first order adsorption. The values of k_{ad} and q_e are determined from the slope and intercept of the plot of $\log (q_e - q_i)$ versus t , respectively. The pseudo-second order model is based on assumption that biosorption follows a second order mechanism. The rate of occupation of adsorption sites is proportional to the square of the number of unoccupied sites. The thermodynamic parameters were obtained by varying the temperature conditions between 25 and 40 °C while keeping other variables constant including metal concentration, pH, adsorbent dosage and contact time. The values of the thermodynamic parameters such as ΔG° , ΔH° and ΔS° were calculated using the expression (Indracanti and Gunturu, 2019).

$$\ln \left(b_M X \frac{1 \text{ mol}}{L} \right) = - \frac{\Delta H^\circ}{R} X \frac{1}{T} + \frac{\Delta S^\circ}{R} \quad (12)$$

$$\Delta G^\circ = - RT \ln (b_M X 1 \text{ mol/L}) \quad (13)$$

$$\Delta G = \Delta H - T \Delta S \quad (14)$$

where b_M is the Langmuir equilibrium constant in L/mol, and the magnitude of K_{eq}° (dimensionless) is numerically equivalent to Langmuir constant (b_M) expressed in L/mol. Utilizing the Langmuir constant as the thermodynamic equilibrium constant, the b_M (L/mol) values of each metal ion were obtained by multiplying b (L/mg) by molecular weight (MW; g/mol) of that metal and 1000, and thermodynamic parameters were calculated by the van't Hoff equation. Where ΔG° is the Gibbs energy change of the process (J mol^{-1}), R is the universal gas constant ($8.314 \text{ J/mol}\cdot\text{K}$), T is the temperature of aqueous phase (in Kelvin), ΔH° is the enthalpy change (J mol^{-1}), and ΔS° is the entropy change (J

$\text{mol}^{-1}\cdot\text{K}^{-1}$). The ΔG° values at higher temperatures represents that the removal process of all studied metal ions is more feasible, more spontaneous and more favorable at the higher studied temperatures. Also, the ΔS° values are positive which may be explained by more randomly organization of the studied metal ions at the solid/solution interface, and the liberation of hydration water molecules during the sorption phenomenon. Also, the sorption processes of all the studied metal ions are endothermic, because their ΔH° values are positive. The ΔG was calculated from the equation at temperature of 303–323 K. The nature of Fe(II) adsorption kinetic process depends on the physical or chemical characteristics of the adsorbent and also on the operating conditions (Lima et al., 2019). For Fe(II) ions adsorption, the values of correlation coefficients of the data, were found to be very high $R^2 = 0.99$. Thermodynamic studies showed that the adsorption process was feasible and exothermic in nature (Lesmana et al., 2009).

6. Deactivation and rejuvenation of biosorbents residual materials

The iron adsorption capacity of biosorbent was highly improved by the change of biosorbent materials residue. The phytotoxicity analysis and amount of iron metals present in the used biosorbent was satisfied the iron-saturated peat (spent sorbent) and it can be applied for ground used those would remove the requirement of costly disposal of material in the landfills. The concentration of iron sorbed depends on the kinetic equilibrium and mixing of the metal at cellular surface area (Buthiyappan et al., 2019). Improvement in the accepting of metabolic pathways of organisms is accountable for metal appropriation, increasing microbial survival rate and their steadiness. The biosorbents deactivation and breakdown over period in their activities is shows in Fig. 19 and producing difficulty in the practice of biosorption procedures. The appropriate life of mango leaf biosorbents is extremely high, those can be specific as the time over which biosorbents substance performances over iron metals biosorption must be maintained (Das et al., 1997).

The deactivation mechanisms happens while the iron molecules turn into reversibly or irreversibly chemisorbed to the active sites, thus declining the amount of sites presence for the reaction. The toxic materials may be a reactant and/or product in the major response or produced impurity in the feed stream. The poisoning is highly effects of reactants, impurities present on the sites or presenting for the biosorbents materials. The iron deposited on the biosorbents surface blocks the active sites and prevents further reactions from taking place, thus “poisoning” and ultimately deactivating of the biosorbents (Allen et al., 2004). The deactivation of different plant leaf biosorbents are shown in Fig. 21 can be applied in theoretical and practical basics for the planning of better-performance residual materials for toxic metal biosorptions. A huge effort has been made to develop the strength of plant leaf biosorbents with the support materials residues. The rejuvenation procedure decreases the metal present with no major changes in the biosorbent residual materials dispersion and restores the performances (Azari et al., 2020).

The different analyses have been made on the rejuvenation and recycle of pretreated mango leaf biomass subsequent to the iron additional. The desorption's analysis also assist to verify the biosorption mechanisms such as ion replace, complexation and physisorption. The major frequent eluents such as diluted HCl, NaOH, HNO_3 and EDTA mixtures, frequently in concentration up to 0.1 mol/L. During the desorption's and recovery of biosorbed iron metals by applying eluents, the steadiness of biosorbent also measured. The repetitive coverage of biosorbents to acidic condition comprised of sturdy desorption agents such as HCl can influence the biomass inflexibility, due to biomass deprivation and reduces in the binding sites. Finally, the rejuvenation of biosorbents to better application takes into the report (Suzuki et al., 2005). So, the rejuvenation of biosorbent with a lower concentration of remaining iron and as a result reapplication of biomass is significant for

economical uses of the procedure. The major reason of this research work is to get the best application of plant leaf biosorbent in iron removal from the water mixtures by the succeeding biosorption desorption cycles in a fixed-bed feature. In purification and breakthrough periods it was observed that the performance was same to the biosorption capability. The rejuvenation of failure plant leaf biosorbent those shows the most excellent biosorption activity in constant mode was calculated in different sorption–desorption cycles by applying the best desorption solution. The rejuvenation of biosorbent and use again in different biosorption–desorption cycles is a significant from the point of analysis to its actual applications (Sud et al., 2008). However, the concern of restoration of biosorbent depends upon the group of aspects as rate of the procedure, declining of the biosorbent, value of recovery metal etc. The several analyses that concerned the utilization of such biosorbents have undertaken previous chemical pretreatment identified as protonation. This procedure is shows in Fig. 22 main objectives to remove more cations such as Ca^{2+} , Na^+ or K^+ from the biosorbent prior to carrying out the biosorption studies to decline the competition of these elements with targeted heavy metals. Furthermore, it leads to the development of lower active sites on the biosorbent surface (at specific pH values) those have superior metal uptake capacity. In addition, the problems of regeneration and difficulty in separation from the wastewater after uses another two major concerns of this material (Zheng et al., 2020).

The main objective was to remove proteins from the biomass sites by caustic purification those increased the biosorption capacity, while the reverse was accurate in place of acidic pretreatment. The addition of Fe^{2+} and Fe^{3+} ions increased with increasing contact period and declining metal ions concentration and stability was getting in the proper contact period. The product is highly significant for together with the biosorbent rejuvenation and sorbate recovery of its assessment (González-Muñoz et al., 2006). The disposal of earth filling and burning could be another used of biosorbent rather than regenerating it. The financial possibility will depend on the biosorption ability, rejuvenation and probable change of the biosorbent. The procedure of biosorption is beneficial due to it is reversible does not need nutrients a distinct procedure of fast range and has no more poisonous effects and cellular expansion. In Fig. 22 shown that the regeneration of mango leaf biosorbents using various treatment processes. The toxicity of iron doesn't present completely in the important formation yet fluctuates unusually between the wide varieties of iron compounds (Polat and Erdogan, 2007). Oxidation state and solvency are major factors in such condition. These conditions are usually founded on physicochemical collaborations between iron metal particles and utilitarian exist on the cell surface, those participates ion-exchange, complexion, electrostatic fascination, and small precipitation. The rejuvenation is normally done by the application of different eluting agents (acids or base) by various desorption mechanisms to discharge the adsorbed iron metal ions into the water solutions. The regeneration of biosorbents shows a financial benefit and is preferred for the practical and commercial applicability in wastewater cleaning procedures (Adegoke and Bello, 2015).

7. Conclusions

The present investigation represents that the potential application of biosorbents for the removal of iron from water solutions. Every biosorbent had different physical, chemical and biological properties for iron removal from water. In present research work, six locally available plant leaf biosorbents i.e. neem leaf, javapalm leaf, guava leaf, sapota leaf, custard apple leaf and mango leaf powdered used for iron removal by the biosorption processes. The order of percentage removal of iron for six different biosorbents was found as Mango leaf > Guava leaf \approx Neem leaf > Java Plum leaf \approx Sapota leaf > Custard Apple leaf. The mango leaf biosorbents show that the best performance for iron removal from water as compared to other biosorbents. So that we used mango leaves biosorbent for optimum sorption of iron from water. In optimization over

mango leaf biosorbents at a basic pH is 5.5, optimum dosage is 4.9g, optimum contact time is 60min, optimum temperature is 25 °C and optimum rotation speed is 150 rpm. This work has been done in a batch type of reactor system. The activity of biosorbents for iron removal from water was in accordance with their characterization. The size of residual particles present in mango leaf biosorbents was 1.18 µm, crystallite size was vary from 4.16 nm, surface area was 43.24 m²/g, pore volume was 0.512 cm³/g and average pore size was 23.46 Å. The reusability of mango leaf biosorbent was also measured, and it was observed that the mango leaf biosorbent does not show any high level of significant changes in its performances even after recycle. The biosorption is an efficient and ecological process for the removal of iron from water due to its easy design and operation. Hence, the present conditions confirm that the mango leaf biosorbents used to remove the iron metal ions from water.

Ethical approval and consent to participate

Not applicable.

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Data availability statement

The statements in the paper are properly cited in the manuscript and no additional data is available.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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