



Industrial Dye Effluents and its Impact- A Mini Review

Radhu Rashini. R¹, R. Amsaveni^{1*}, V. Bhuvaneshwari¹, M. Kalaiselvi²

¹PG and Research Department of Biotechnology, Kongunadu Arts and Science College, Coimbatore - 641029, Tamil Nadu, India.

²Department of Biochemistry, Kongunadu Arts and Science College, Coimbatore - 641029, Tamil Nadu, India.

Received: July 2017; Accepted; Aug 2017

*Author to whom corresponding should be addressed

Email: amsabiotech@gmail.com

Abstract: Ecotoxicological impacts of industrial effluents on the aquatic lives are not in safe. Approximately 10 to 15% of the dyes are released into the aquatic environment during dye processing in various industries and the effluents have been reported to be highly toxic to aquatic organisms and some of the dyes have carcinogenic and mutagenic effects to causes the disease. Several reports emphasise that the wastewater generated from tanneries, textile and paper industries are found to have intense colours of various shades through the production of different colour containing dyes with high level of COD, BOD chlorides, phenolic compounds and various heavy metals. The removal of colour from wastewater is the need of the hour and its poises a great challenge in the current scenario. On the other hand condition using microorganism lead to aromatic amine formation and these are mutagenic and toxic to human Apparently there is a need for develop novel biological decolourization processes leading to the more effective cleaning up for industrial dyes. Several biological systems including bacteria fungi and algae are used in these regarded.

Keywords: Industrial effluents, environment, organisms, toxic, biological systems

1. Textile effluent

The effluent of textile industries dispose a large amount of dye contents which on mixing with water bodies cause severe problems such as increase in Chemical Oxygen Demand and reducing light penetration and visibility (Murray and Parsons. 2004) which hampers the photosynthetic process, causing alteration in the habitat Therefore, an efficient pretreatment or polishing process is required to decolorize the highly coloured wastewater from textile dyeing industries. In recent years, the iron oxide nanoparticles have attracted researchers from various fields such as physics, medicine and material science due to their multifunctional properties with small size, and low toxicity (Kang *et al.*, 1996; Willner and Katz, 2003). Iron nanoparticle is widely used in the field of biomedical applications such as protein and enzyme immobilization, bioseparation, immunoassay, drug delivery, magnetic resonance imaging (MRI). Chemicals

such as Ferric chloride (FeCl_3) are used as further purification (Dobson, 2006; Park and Lim, 2006).

The effluent of textile industries dispose a large amount of dye contents which on mixing with water bodies cause severe problems such as increase in Chemical Oxygen Demand and reducing light penetration and visibility which hampers the photosynthetic process, causing alteration in the habitat Therefore, an efficient pretreatment or polishing process is required to decolorize the highly coloured wastewater from textile dyeing industries. The synthesis of nanoparticles using plant extracts is advantageous over microorganisms by eliminating the elaborate process of maintaining microbial culture. Nanoparticles and their applications have gained much importance in recent decades. The properties of bulk materials changed when brought to the nano range. A nano particle has at least

one of its dimensions less than 100 nm, but new applications use particles in the range of few hundred nanometers. Synthetic dyes comprise an important part of industrial water effluents that are discharged by many manufacturing industries. The impact of these dyes on the environment is a major concern because of the potentially carcinogenic properties of the chemicals (Parsons, 2004). Also, some dyes can undergo anaerobic decolouration to form potential carcinogens (ZubairAlam and Ahmad, 2010).

Large amounts of chemically different group of dyes such as azo, disperse, acidic, basic, triphenylmethane were used for dyeing. According to Global Industry Analysts, the production of worldwide synthetic dyes and pigments industries is predicted to reach almost 10 million tons by 2017 which will be worth close to \$27 billion. More than 11 % of these compounds produced annually is lost to effluents during application processes. The presence of even small amounts of dyes in water (<1 ppm) is visible. It affects the aesthetic value, causes loss in luminosity, decreases oxygen solubility in water and blocks the passage of light to the lower depths of aquatic systems.

Synthetic dyes are preferred for use over natural dyes due to their superior performance. As compared to natural dyes, synthetic dyes impart brighter colors, show better light-fastness and are more resistant to washing. Also, synthetic dyes offer a wider variety of colors. Wastewater or effluents from industries that manufacture paints, pigments and color cosmetics contain a variety of synthetic dyes. Industries involved in dyeing of textile, paper, leather and plastics, release effluents that are highly coloured. The removal of colouring matter from effluent is a major problem faced by industries. Due to their chemical structures such as conjugated double bonds and aromatic rings, dyes are resistant to fading on exposure to light, water and many chemicals. It is difficult to be decolourized once released into aquatic environment as it disturbs aquatic ecosystem. In addition they are toxic to humans also.

Methods for treating textile dye wastewaters consist of various chemical, physical and biological processes. Because of the high cost, disposal problems and

generation of toxic products most of the chemical and physical methods for treating dye waste are not widely used (Robinson *et al.*, 2001).

In recent years, the use of living systems such as microorganisms and plants to degrade recalcitrant pollutants is gaining importance as a viable alternative to existing physico-chemical removal methods. Stringent government policies regarding permitted levels of pollutants, high costs of specialized chemical treatments for pollutant removal and the fact that some of these treatments create additional solid waste has led to the development of many effective, yet simple biological methods. Wastewater from textile industries poses a threat to the environment as large amount of chemically different dyes are used for various industrial applications and a significant proportion of these dyes enter the environment via wastewater. Around 10-15% of all the dyes used in the industry are lost within wastewater during synthesis and processing. The presence of even very low concentrations of dyes in effluent is highly visible and degradation products of these textile dyes are often carcinogenic.

There are more than 10,000 commercially available dyes with over 7×10^5 tones of dyestuff produced annually across the world. With the increased use of a wide variety of dyes, pollution by dye wastewater is becoming increasingly alarming. Thus, there is an urgent need to develop effective methods to treat these toxic textile effluents. Metal nanoparticles have found extensive use in different applications owing to their typical optical, electrical and magnetic properties (Alivisatos, *et al.*, 1996; Fernández, *et al.*, 2004; Devasenan, *et al.*, 2016). Different transition metal oxides including iron oxide nanoparticles (FeONPs) have been focused in various applications such as sensors (Chen, *et al.*, 2005), catalysts (Sugimoto, 1999), in wastewater treatment (Cheng, *et al.*, 2016), in energy storage (Yousefi, *et al.*, 2013), in tumor detection (Ghazani, *et al.*, 2014) and as antimicrobial agents (Tran, *et al.*, 2010).

Dyes used in various industries showed their presence at a reasonable level in waste water even after treatment and pose a serious threat to the environment. These dyes

are known to cause major health problems in humans which include carcinogenic and mutagenic effects (Chu and Ma, 2000; Puvaneswari, *et al.*, 2006). Conventional dye degradation techniques such as coagulation, flocculation, adsorption and membrane filtration (Gupta *et al.*, 2009) not only uses hazardous chemicals, but also results in incomplete degradation of dyes. Hence greener methods using biocompatible catalysts are of great interest in recent time's especially metal/ metal oxides in degradation methods. Reports are available on the degradation of methyl orange and malachite green using iron oxide nanoparticles (Shahwan *et al.*, 2011; Huang and Weng, 2014) synthesized through chemical methods as well as green methods.

2. Nanotechnology for effluent treatment

In nanotechnology, the particles are defined as a small object that acts as a whole unit with respect to its transport and properties. Nanotechnology is a multidisciplinary branch of science which deals with synthesis, analyze nanomaterials and their novel properties that is different from the bulk material from which it is produced, and thus lead to many applications ranging from biomedical (Conde, *et al.*, 2012), waste treatment (Rajan, 2011), electronics (Frey and Sun, 2009), catalysis (Shahwan, *et al.*, 2011), sensors (Park, *et al.*, 2014) etc. Nanoparticles (NPs) are particles between 1 to 100 nanometers in size. The nanoparticles may be metals, semiconductors or insulators. Iron oxide nanoparticles play an important role in environmental remediation circles. As it removes both of organic and inorganic heavy metal pollutants from polluted water (Xu *et al.*, 1984).

With the recent rapid development and evolvement of technology, human beings have put their faith in nanotechnology and believe that it can ameliorate their current living standard (Priest, 2006). As a consequence, the nanoparticle has drawn a huge interest from researchers globally due to specific characteristics such as shape, size, and distribution, which could be utilized in a distinct field of applications (Zargar *et al.*, 2011).

Synthesis of Fe₃O₄-NPs has been carried out because of its unique properties, such as

being superparamagnetic (Mahdavian and Mirrahimi, 2010), biocompatible, biodegradable, and expected to be non-toxic to humans (Hu, *et al.*, 2006; Zhang *et al.*, 2013). These unique properties allow Fe₃O₄-NPs to be widely used in different areas of applications, such as catalysis (Gawande, Varma, 2013; Sharad *et al.*, 1706) magnetic storage media (Terris and Thomson, 2005), biosensors (Kavitha, *et al.*, 2013) and magnetic resonance imaging (MRI) (Haw *et al.*, 2010; Qiao *et al.*, 2009).

Globally, it is estimated that over 7×10^5 ton and approximately 10,000 different dyes and pigments are produced annually world-wide, it is estimated that 2-50% of them are lost into wastewaters, causing environmental contaminations (Deveci *et al.*, 2004). Discharge of dyes into the aquatic or other environment causes serious problems, since they may affect the photosynthetic activity of hydrophytes by reducing light penetration intensity (Aksu *et al.*, 2007) and also they may be toxic to aquatic fauna and flora due to their breakdown products such as metals and chlorides (Hao *et al.*, 2000; Dhaneshvar *et al.*, 2007).

Color is the first contaminant to be recognized in wastewater and has to be removed before discharging into water bodies or on land. The removal of color from wastewater is often more important than the removal of the soluble colorless organic substances, which usually contribute the major fraction of the biochemical oxygen demand. Many methods have been reported for removing textile dyes from wastewater, among which biological techniques include bacterial and fungal biosorption and biodegradation in aerobic, anaerobic or combined anaerobic/aerobic treatment processes. The use of one individual process may often not be sufficient to achieve complete decolorization. Also the economic condition of the process must be taken into account as we can't spend a lot of money in clearing. So an economic method is also required.

3. Applications and toxicity of synthetic dyes

Large amounts of chemically different group of dyes such as azo, disperse, acidic, basic, triphenylmethane were used for textile dyeing. Most coloured textile and leather

articles are treated with azo dyes and pigments. Bromophenol blue (3',3'',5',5''-tetrabromophenolsulfonphthalein) is used as a pH indicator and also used as a color marker to monitor the process of agarose gel electrophoresis and polyacrylamide gel electrophoresis. Methylene blue is redox aniline dye (C₁₆H₁₈N₃SCl.3H₂O). It is not regarded as acutely toxic, but it can have various harmful effects (Sarioglu and Atay, 2006). Coomassie Brilliant Blue is the name of two similar triphenylmethane dyes that were developed for use in the textile industry but are now commonly used for staining proteins in analytical biochemistry.

Triarylmethane dyes are synthetic organic compounds containing triphenylmethane backbones. Phenol red (phenolsulfonphthalein) is a pH indicator frequently used in cell biology laboratories. Phenol red is used for the detection, identification, analysis, etc. of chemical, biological, or pathologic processes or conditions. No systemic toxicity has been reported after oral doses except for occasional allergic reactions. Among many classes of synthetic dyes used in the textile and dyeing industries, triaryl methane group of dyes such as crystal violet and malachite green are the largest and most versatile and play a predominant role in almost every type of application (Bumpus and Brock, 1988).

Malachite green is traditionally used as a dye for materials such as silk, leather, and paper. It is classified in the dyestuff industry as a triarylmethane dye and also using in pigment industry. Malachite green, a mineral banned for human consumption, is a carcinogen. It is used extensively in India in the dyeing of cotton, wool, jute and leather, as well as an antiseptic. The Cancer Research Institute and the Tata Memorial Hospital of India have conducted experiments using malachite green that resulted in malignant transformation of Syrian hamster embryo cells. The chemical, also used surreptitiously in colouring sweets, poses a considerable risk to workers in printing and textile industries.

Methyl violet 10B also called as Crystal violet (N, N, N1, N1, N11, N11 - hexamethyl-para-rosaniline) has been extensively used in human and veterinary medicine as a biological stain (Bangert *et al.*, 1977; Eiichi *et al.*, 1985). It is used to dye paper and as a

component of navy blue and black inks for printing, ball-point pens and ink-jet printers. It is also used to colourize diverse products such as fertilizers, anti-freezes, detergents, and leather jackets. Like malachite green, crystal violet is readily absorbed into fish tissue from water exposure and is reduced metabolically by fish to the leuco moiety, leucocrystal violet.

Several studies by the National Toxicology Program reported that the carcinogenic and mutagenic effects of crystal violet in rodents. The leuco form induces renal, hepatic and lung tumor in mice. Some triaryl methane dyes have been shown to be carcinogenic especially crystal violet which has been proved to be potent carcinogen (Au *et al.*, 1978).

Congo red dye (sodium salt of benzinediazo-bis-1-naphthylamine-4-sulfonic acid, C₃₂H₂₂N₆Na₂O₆S₂) is a typical diazo dye with two chromophoric groups (azo group) in its structure. It is highly soluble in water and persistent when once discharged into a natural environment (Tapalad *et al.*, 2008; Jalandoni-Buan *et al.*, 2009; Tang *et al.*, 2011). Congo Red is an azo dye with a structure 3, 3'-((biphenyl)-4,4'-diylbis(azo))-bis(4-amino-1-naphthalenesulphonicacid) disodium salt. It is intended primarily for the coloration of paper products, used in medicine (as a biological stain) and as an indicator since it turns from red-brown in basic medium to blue in acidic, used to color textile and wood pulp. It is a recalcitrant and act as potent carcinogen and mutagenic because of the presence of aromatic amine group (Cripps *et al.*, 1990).

Azo dyes have long been recognized as a human urinary bladder carcinogen and Tumorigenic in animals (Puvanewari *et al.*, 2006) cyanogenic in fishes, reduction in seed germination and induce dwarfism in plants (Nirmalarani and Janardhanan, 1988). Azo dyes feature among the most widely used synthetic dyes in industry globally. The fixation of azo dyes (on textile) is quite low and often, up to 50% of the applied dye may be lost in the wash stream. Safranines are the azonium compounds of symmetrical 2,8-dimethyl-3,7-diamino-phenazine.

Safranin (also Safranin O or basic red 2) is a biological stain used in histology and cytology. Safranin is used as a counter stain

in Gram staining protocols, coloring all cell nuclei red. It is also used for the detection of cartilage, mucin and mast cell granules. The presence of safranin causes several acute effects on health (like irritation to mouth, throat and stomach with effects including mucous build up, irritation to the tongue and lips and pains in the stomach, which may lead to nausea, vomiting and diarrhea, irritation to the eyes, with effects including: tearing, pain, stinging and blurred vision, redness and itchiness of skin (Rejniak and Piotrowska, 1966).

Acknowledgement: Authors are thankful to the Secretary, Principal and Department of Biotechnology of Kongunadu Arts and Science College for providing facilities.

REFERENCES

- Aksu, Z., Kilic, N.K., Ertugrul, S. and Donmez, G. 2007. Inhibitory effects of chromium (VI) and remazol black B on chromium (VI) and dyestuff removals by *Trametes versicolor*. *Enzyme and Microbial Technology*, 40:1167-1174.
- Alam, Z. M., Ahmad, S., Malik, A. and Ahmad, M. 2010. Mutagenicity and genotoxicity of tannery effluents used for irrigation at Kanpur, India. *Ecotoxicology and Environmental Safety*. 73:1620, 7:1628.
- Alivisatos, A.P. 1996. Semiconductor clusters, nanocrystals, and quantum dots. *Science*. 271:933-937.
- Borchert, M. and Libra, J.A. 2001. Decolorization of reactive dyes by the white rot fungus *Trametes versicolor* in sequencing batch reactors. *Biotechnology and Bioengineering*. 5;75(3):313-321.
- Bumpus, J.A. and Brock, B.J. 1988. Biodegradation of crystal violet by the white rot fungus *Phanerochaete chrysosporium*. *Applied Environmental Microbiology*, 54(5):1143-1150.
- Chen, J., Xu, L., Li, W. and Gou, X. 2015. α -Fe₂O₃ nanotubes in gas sensor and lithium-ion battery applications. *Advanced Materials*. 17:582-586.
- Cheng, Z., Tan, A.L.K., Tao, Y., Shan, D., Ting, K.E. and Yin, X.J. 2012. Synthesis and characterization of iron oxide nanoparticles and applications in the removal of heavy metals from industrial wastewater. *International Journal of Photoenergy*. 1-5.
- Chu, W. and Ma, C. 2000. Quantitative prediction of direct and indirect dye ozonation kinetics. *Water Research*. 34:3153-3160.
- Conde, J., Doria, G. and Baptista, P. 2012. Noble metal nanoparticles applications in cancer. *Journal of Drug Delivery*. 1-12.
- Cripps, C., Bumpus, J.A. and Aust, S.D. 1990. Biodegradation of azo and heterocyclic dyes by *Phanerochaete chrysosporium*. *Applied Environmental Microbiology*. 56(4): 1114-1118.
- Devasanan, S., Hajara Beevi, N. and Jayanthi, S.S. 2016. Synthesis and characterization of silver nanoparticles by chemical reduction method and their antimicrobial activities. 9:571-576.
- Deveci, T., Unyayar, A. and Mazmanci, MA. 2004. Production of remazol brilliant blue decolorising oxygenase from the culture filtrate of *Funalia trogii* ATCC 200800. *Journal of Molecular Catalysis B: Enzymatic*, 30: 25-32.
- Dhaneshvar, N., Ayazloo, M., Khatae, A.R. and Pourhassan, M. 2007. Biological decolorization of dye solution containing malachite green by microalgae *Cosmarium* sp. *Bioresource Technology*, 29:1-7.
- Do, T., Shen, J., Cawood, G. and Jeckins, R. 2002. Biotreatment of textile effluent using *Pseudomonas* spp. Immobilized on polymer supports. In: Hardin, I.R., Akin, D.E. and Wilson, J. (Eds). *Adv. Biotreat. Text.Process.* University of Georgia press.
- Dobson, J. 2006. Magnetic nanoparticles for drug delivery. *Drug Delivery Research*. 67:55.
- Fajardo, C., Sacca, M.L., Martinez-Gomariz, M., Costa, G., Nande, M. and Martin, M. 2013. Transcriptional and proteomic stress responses of a soil bacterium *Bacillus cereus* to nanosized zero-valent iron (nZVI) particles. *Chemosphere*. 93:1077-1083.
- Fernández-García, M., Martínez-Arias, A., Hanson, J.C. and Rodríguez J.A. 2004. Nanostructured oxides in chemistry: characterization and properties, *Chemicals Reviews*. 104:4063-4104.
- Frey, N. and Sun, M. 2009. Shouheng materials, magnetic nanoparticle for information storage applications. 33-68.
- Gawande, M.B. and Varma, R.S. 2013. Nano-magnetite (Fe₃O₄) as a support for recyclable catalysts in the development of sustainable methodologies. *Chemical Society Reviews*. 42(8):3371-3393.
- Ghazani, AA., Pectasides, M., Sharma, A., Castro, C.M., Mino-Kenudson, M., Lee, H., Shepard, J.A. and Weissleder, R. 2014. Molecular characterization of scant lung tumor cells using iron-oxide nanoparticles and micro-nuclear magnetic resonance. 10:661-668.
- Gupta, V.K. and Suhas. 2009. Application of low-cost adsorbents for dye removal-A review. *Journal of Environmental Management*. 90:2313-2342.
- Hao, O.J., Kim, H. and Chiang, P.C. 2000. Decolorization of wastewater. *Critical Reviews in Environmental Science and Technology*, 30:449-505.
- Haw, C.Y., Mohamed, F., Chia, C.H., Radiman, S., Zakaria, S., Huang, N.M. and Lim, H.N. 2010. Hydrothermal synthesis of magnetite nanoparticles as MRI contrast agents. *Ceramics International*. 36(4):1417-1422.
- Hu, F.Q., Wei, L., Zhou, Z., Ran, Y.L., Li, Z. and Gao, M.Y. 2006. Preparation of biocompatible magnetite nanocrystals for in vivo magnetic resonance detection of cancer. *Advanced Materials*. 18(19):2553-2556.
- Huang, L.L., Weng, X.L., Chen, Z.L., Megharaj, M. and Naidu R. 2014. Synthesis of iron based nanoparticles using oolong tea extract for the degradation of malachite green. *Spectrochim. Acta Part A*. 117:801-804.
- Kang, Y.S., Risbud, S., Rabolt, J.F. and Stroeve, P. 1996. Synthesis and characterization of nanometersize Fe₃O₄ and g-Fe₂O₃ particles. *Chemistry of Materials*. 8:2209.
- Kavitha, A.L., Prabu, H.G., Babu, S.A. and Suja, S.K. 2013. Magnetite nanoparticles-chitosan composite containing carbon paste electrode for glucose biosensor application. *Journal of Nanoscience and Nanotechnology*. 13(1):98-104.
- Mahdavi, M., Ahmad, M.B. and Haron, M.J. 2013. Synthesis, surface modification and characterisation of biocompatible magnetic iron oxide nanoparticles

- for biomedical applications. *Molecules*. 18(7):7533-7548.
- Mahdavian, A.R. and Mirrahimi, M.A.S. 2010. Efficient separation of heavy metal cations by anchoring polyacrylic acid on superparamagnetic magnetite nanoparticles through surface modification. *Chemical Engineering Journal*. 159(1):264-271.
- Manas, M. and Pleixats, R. 2003. Formation of carbon - carbon bonds under catalysis by transition - metal nanoparticles. *Accounts of Chemical Research*, 36:638.
- Murray, C.A. and Parsons, S.A. 2004. Advanced oxidation processes: flowsheet options for bulk natural organic matter removal. *Water Supply*. 4:113.
- Nirmalarani, J. and Janardhanan, K. 1988. Effect of South India viscose factory effluent on seed germination, seedling growth and chloroplast pigments contents in fire varieties of maize (*Zea mays* L.). *Madras Agricultural Journal*, 75(1-2): 41-47.
- Park, H., Kim, J., Jung, H., Seo, J. and Choi, H. 2014. Iron oxide nanoparticle-impregnated alumina for catalytic ozonation of para-chlorobenzoic acid in aqueous solution. *Water, Air, Soil Pollution*. 225.
- Park, S.I., Lim, J.H. and Kim, C.O. 2008. Surface-modified magnetic nanoparticles with lecithin for applications in biomedicine. *Current Applied Physics*. 8:706.
- Parsons, S. 2004. *Advanced oxidation processes for water and wastewater*. IWA Publishing, London.
- Priest, S. 2006. The North American opinion climate for nanotechnology and its products: opportunities and challenges. *Journal of Nanoparticles Research*. 8(5):563-568.
- Puvaneswari, N., Muthukrishnan, J. and Gunasekaran, P. 2006. *Indian Journal of Experimental Biology*, 44:618-626.
- Puvaneswari, N., Muthukrishnan, J. and Gunasekaran, P. 2006. Toxicity assessment and microbial degradation of azo dyes. *Indian Journal of Experimental biology*. 44:618-626.
- Qiao, R.R., Yang, C.H. and Gao, M.Y. 2009. Superparamagnetic iron oxide nanoparticles: from preparations to in vivo MRI applications. *Journal of Materials Chemistry*. 19(35):6274-6293.
- Rajan, C. S. 2011. Nanotechnology in groundwater remediation. *International Journal of Environmental Science and Development*. 2,3:182-187.
- Rao, C.N.R. and Cheethan, A.K. 2001. Science and technology of nanomaterials, current status and future prospects. *Journal of Materials Chemistry*. 11:2887.
- Rejniak, L. and Piotrowska, H. 1966. Effect of malachite green, congo red and safranin on cell division in gemmae of *Allium cepa*. *Nature* 209: 517 – 518.
- Robinson, T., McMullan, G., Marchant, R. and Nigam, P. 2001. Remediation of dyes in textile effluents: a critical review on current treatment technologies with a proposed alternative. *Bioresource Technology*, 77(3): 247-255.
- Sacca, M.L., Fajardo, C., Costa, G., Lobo, C., Nande, M. and Martin, M. 2014. Integrating classical and molecular approaches to evaluate the impact of nanosized zero-valent iron (nZVI) on soil organisms. *Chemosphere*. 104:184-189.
- Sarioglu, M. and Atay, U.A. 2006. Removal of methylene blue by using biosolid. *Global Nest Journal*, 8(2):113-120.
- Shahwan, T., Abu Sirriah, S., Nairat, M., Boyaci, E., Eroglu, A.E., Scott, T.B. and Hallam, K.R. 2011. Green synthesis of iron nanoparticles and their application as a fenton-like catalyst for the degradation of aqueous cationic and anionic dyes. *Chemical Engineering Journal*. 172:258-266.
- Shahwan, T., Abu Sirriah, S., Nairat, M., Boyaci, E., Eroglu, A. E., Scott, T. B. and Hallam, K. R. 2011. Green Synthesis of iron nanoparticles and their application as a Fenton-like catalyst for the degradation of aqueous cationic and anionic dyes. *Chemical Engineering Journal*. 172:258-266.
- Sharad, N.S., Swapnil, R.B., Ganesh, R.M., Samadhan, S.K., Dinesh, K.M., Shashikant, B.B., Anuj, K.R., Nenad, B., Orlando, M.N.D.T., Radek, Z., Rajender, S.V. and Manoj, B.G. 2014. Iron oxide-supported copper oxide nanoparticles (nanocat-Fe-CuO): magnetically recyclable catalysts for the synthesis of pyrazole derivatives, 4-methoxyaniline, and ullmann-type condensation reactions. *ACS Sustainable Chemical Engineering*. 2(7):1699-1706.
- Srivastava, N. 2014. Iron nanoparticles induced toxicity in *Sesbania cannabina*: a morphological aspect. *Advanced Science Focus*. 2(2):135-139.
- Sugimoto, M. and Am Cerem, J. 1999. The past, present and future of ferrites. *System on a chip*. 82:269-280.
- Terris, B.D. and Thomson, T. 2005. Nanofabricated and self-assembled magnetic structures as data storage media. *Journal of Physics D:Applied Physics*. 38(12):199-222.
- Tran, N., Mir, A., Mallik, D., Sinha, A., Nayar, S. and Webster, T. 2010. Bactericidal effect of iron oxide nanoparticles on staphylococcus aureus. *International Journal of Nanomedicine*. 5:277-283.
- Willner, I. and Katz, E. 2003. Magnetic control of electrocatalytic and bioelectrocatalytic processes. *Angewandte Chemie International Edition*. 42:4576.
- Xu, P., Zeng, G. M., Huang, D. L., Feng, C. L., Hu, S., Zhao, M.H., Lai, C., Wei, Z., Huang, C., Xie, G.X. and Liu, Z.F. 1984. Use of iron oxide nanomaterials in wastewater treatment. *Science of The Total Environment*. 1(424):1-10.
- Yousefi, T., Golikand, A.N. and Mashhadizadeh, M.H. 2013. Synthesis of iron oxide nanoparticles at low bath temperature, characterization and energy storage studies. *Material Science in Semiconductor Process*. 16:1837-1841.
- Zargar, M., Hamid, A.A., Bakar, F.A., Shamsudin, M.N., Shameli, K., Jahanshiri, F. and Farahani, F. 2011. Green synthesis and antibacterial effect of silver nanoparticles using *Vitex negundo* L. *Molecules* 16(8):6667-6676.
- Zhang, L., Dong, W.F. and Sun, H.B. 2013. Multifunctional superparamagnetic iron oxide nanoparticles: design, synthesis and biomedical photonic applications. *Nanoscale* 5(17):7664-7684.

