Scientific Review
ISSN(e): 2412-2599, ISSN(p): 2413-8835
Vol. 7, Issue. 3, pp: 20-31, 2021
URL: https://arpgweb.com/journal/journal/10
DOI: https://doi.org/10.32861/sr.73.20.31

Academic Research Publishing Group

A Review **Open Access**

A Review on the Methods of Industrial Waste Water Treatment

Khandakar M. Nahiun
Institute of Radiation and Polymer Technology, Atomic Energy Research Establishment, Savar, Dhaka, Bangladesh
National Institute of Textile Engineering and Research, Nayarhat, Savar, Dhaka 1350, Bangladesh

Bijoyee Sarker
Institute of Radiation and Polymer Technology, Atomic Energy Research Establishment, Savar, Dhaka, Bangladesh
National Institute of Textile Engineering and Research, Nayarhat, Savar, Dhaka 1350, Bangladesh

Kamrun N. Keya
Institute of Radiation and Polymer Technology, Atomic Energy Research Establishment, Savar, Dhaka, Bangladesh

Fatin I. Mahir
Institute of Radiation and Polymer Technology, Atomic Energy Research Establishment, Savar, Dhaka, Bangladesh
National Institute of Textile Engineering and Research, Nayarhat, Savar, Dhaka 1350, Bangladesh

Shahirin Shahida
Department of Mechatronics Engineering, Kyungsung University,309 Suyeong-ro, Nam-gu, Busan-48434, Republic of Korea

Ruhul A. Khan (Corresponding Author)
Institute of Radiation and Polymer Technology, Atomic Energy Research Establishment, Savar, Dhaka, Bangladesh
Email: dr.ruhul_khan@yahoo.com

Article History
Received: 18 April, 2021
Revised: 9 June, 2021
Accepted: 27 June, 2021
Published: 4 July, 2021

Abstract

Nowadays environmental pollution is a great threat to us. Water resources are mostly polluted by industrial wastes. Among all other pollutions, water pollution is one of the most vital pollution caused by different sources like industrial, domestic, sewage, hazardous waste, municipal waste, medical waste, manufacturing waste, etc. Public concern over the impact of wastewater has increased. There are several methods for the treatment of wastewater. Among them, techniques like coagulation, adsorption, activated sludge are prominent. The use of aerobic wastewater treatment as a reductive medium is receiving attention for its low cost of operation and low cost of maintenance. The uses of low-cost adsorbents are also effective in wastewater treatment. The aerobic wastewater is effective in degrading the contaminants. There are different electrolytic techniques as well for wastewater treatment. This paper reviews the possible techniques available for the treatment of wastewater to remove contaminants such as halogenated hydrocarbon compounds, heavy metals, dyes, pigments etc. from the wastewater.

Keywords: Industrial waste water; Adsorption; Filtration; Treatment; Environmental pollution.

1. Introduction

A supply of clean water is an obvious requirement for the establishment and maintenance of diverse human activities. Water resources offer valuable food over aquatic life and irrigation for agriculture production. However, liquid and solid wastes made by human settlements and industrial activities pollute maximum of the of the water sources throughout the world. Due to massive worldwide increases in the human population, water will become one of the scarcest resources in the 21st century [1]. In the year 2015 the mainstream of the global population (over 5 billion) will live in urban environments. By the end of year 2015, there will be 23 megacities with a population of over 10 million each, 18 of which will exist in the developing world [2]. Central to the urbanization phenomena are the problems associated with providing municipal services and water sector infrastructure, including the provision of both fresh water resources and sanitation services. Currently, providing housing, health care, social services, and access to basic human needs infrastructure, such as clean water and the disposal of effluent, presents major challenges to engineers, planners and politicians [1].

As human numbers increase, greater strains will be placed on available resources and pose even greater threat to environmental sources. A report by the Secretary-General of the United Nations Commission on Sustainable Development concluded that there is no sustainability in the current uses of fresh water by either developing or developed nations, and that worldwide, water usage has been growing at more than three times the world's population increase, consequently leading to widespread public health problems, limiting economic and agricultural development and adversely affecting a wide range of ecosystems. Much of the wastes of civilization enter water bodies through the discharge of waterborne waste from domestic, industrial and non-point sources carrying unwanted and unrecovered substances. Although the collection of wastewater dates back to ancient times, its treatment is a relatively recent development dating from the late 1800s and early 1900s [3]. Recent information of the need for sanitation and treatment of polluted waters however, started with the frequently cited case of John Snow in 1855, in which he proved that a cholera outbreak in London was due to sewage adulterated water acquired from the Thames River . In developed nations, treatment and discharge systems can sharply differ between countries and between rural and urban users, with respect to urban high income and urban low-income users [3]. The most common wastewater treatment methods in developed countries are centralized aerobic wastewater treatment plants and lagoons for both domestic and industrial wastewater [3].

In many developing countries, the bulk of domestic and industrial wastewater is directly discharged into water streams without go through any treatment processes or after primary treatment only. Even a highly industrial prone country such as China, approximately 55% of their sewage was discharged without any treatment. The discharge of untreated wastewater to the water bodies without any treatment processes will leads to several environmental problems such as

1. Untreated wastewater which contains a large amount of organic matter will consume the dissolved oxygen for satisfying the biochemical oxygen demand (BOD) of wastewater and thus, deplete the dissolved oxygen of the water stream required by the aquatic lives.
2. Untreated wastewater usually contains a large amount of pathogenic or disease causing microorganisms and toxic compounds, that can dwell in the human intestinal tract thus threatening the human health.
3. Wastewater may also contain certain amount of nutrients, which can stimulate the growth of aquatic plants and algal blooms, thus, leading to eutrophication of the lakes and streams.
4. The decomposition of the organic compounds present in wastewater can lead to the production of large quantities of malodorous gases.

For centuries wastewater management was not given much consideration. In most cultures, wastewater was disposed of in the streets and near population centers creating serious impacts on public health and the environment. This is apparent by the numerous epidemics which occurred throughout Europe until the nineteenth century. Sadly, when it came to waste management and sanitation, countries, even those that suffered epidemics, tended to have short memories. Throughout history wastewater management has presented people and governments with far reaching technical and political challenges. The story of waste and wastewater management is at once a story of human ingenuity and human frailty [4]. A number of keystone events defined the speed at which environmental management evolved through the ages. Some of these events were scientific, such as stream purification models, while others were socioeconomic such as two World Wars. However according to the recent Human Development Report (2006), the lesson from the past is that progressing wastewater management and sanitation was driven above all by political coalitions uniting industrialists, municipalities and social reformers. This means that if on one side developing new technologies as well as appropriate approaches for wastewater management is required, on the other hand there must be an urgent need to overcome the disgrace of a polluted environment [4].

Therefore, the treatment of wastewater is a must before leaving it enters the natural water bodies. Different physical and chemical treatment methods have been reviewed for the treatment of wastewater such as biological degradation, ion exchange, chemical precipitation, adsorption, reverse osmosis, coagulation, flocculation, etc. All these treatment methods have different performance characteristics and also different direct impacts on the environment. This review will particularly discuss the application of biofilm technology, bio granulation and microbial fuel cell (MFC) for the treatment of waste water [4].

1.1. Waste Water Global Trends

On average, high-income countries treat about 70% of the municipal and industrial wastewater they generate. That ratio drops to 38% in upper middle-income countries and to 28% in lower middle-income countries. In low-income countries, only 8% undergoes treatment of any kind. These estimations support the often-cited approximation that, worldwide, over 80% of all wastewater is discharged without treatment. In high-income countries, the inspiration for advanced wastewater treatment is either to maintain environmental quality, or to provide an alternative water source when managing with water scarceness. However, the release of untreated wastewater remains common practice.

Overcoming the practical difficulties of implementing water quality regulations can be particularly challenging. In order to realize the goals of water quality improvement and water resources protection, individuals and Organization responsible for various aspects of wastewater management need to comply and act in the collective interest. Benefits are only realized once everyone abides by the rules to protect water resources from pollution.

Involving people in decision-making at all levels stimulates engagement and ownership. This includes decisions as to what types of sanitation facilities are desirable and acceptable, and how they can be securely funded and maintained over the long term. It is especially important to reach out to marginalized groups, ethnic minorities and people living in extreme poverty, in remote rural areas or in informal urban settlements. It is also essential to engage with women, as they bear the brunt of the health of the consequences stemming from the unsafe management of human waste.

1.2. Wastewater and Sustainable Development Agenda

Access to improved sanitation services can contribute significantly to the reduction of health risks. Further health gains may be realized through improved wastewater treatment. While 2.1 billion people gained access to improved sanitation facilities since 1990, 2.4 billion still do not have access to improved sanitation and nearly 1 billion people worldwide still practice open defecation.

However, improved sanitation coverage does not necessarily equate with improved wastewater management or public safety. Only 26% of urban and 34% of rural sanitation and wastewater services successfully thwart human contact with excreta along the entire sanitation chain and can therefore be considered safely managed. However, improved sanitation coverage does not necessarily equate with improved wastewater management or public safety. Only 26% of urban and 34% of rural sanitation and wastewater services effectively prevent human contact with excreta along the entire sanitation chain and can therefore be considered safely managed.

1.3. Technical Aspects of the Wastewater Management Cycle

Wastewater is roughly composed of 99% water and 1% suspended, colloidal and dissolved solids. The consequences of releasing untreated or inadequately treated wastewater can be classified into three groups: i) harmful effects on human health; ii) negative environmental impacts; and iii) adverse repercussions on economic activities. Controlling and regulating various wastewater flows is the ultimate purpose of wastewater management. The wastewater management cycle can be broken down into four basic interconnected phases

1. **Prevention or Reduction of Pollution at the Source*:*** Approaches to water pollution control that focus on wastewater prevention and minimization should be given priority over traditional end of-pipe treatment whenever possible. These approaches include prohibiting or controlling the use of certain contaminants to eliminate or limit their entering into wastewater streams through regulatory, technical and/or other means. Remedial actions to clean up polluted sites and water bodies are generally much more expensive than measures to prevent pollution from occurring. Monitoring and reporting of pollutant discharges to the environment and ambient water quality are necessary to achieve progress. If something is not measured, the problem cannot be defined and the effectiveness of policies cannot be assessed.

2. Wastewater Collection and Treatment

Centralized waterborne waste disposal remains the prevalent method for sanitation and for evacuating wastewater from domestic, commercial and industrial sources. Globally, about 60% of people are connected to a sewer system (although only small proportion of the collected sewerage is actually treated). Other sanitation options, such as on-site systems, are well-suited to rural areas and low population density settings, but can be expensive and difficult to manage in dense urban environments. Large-scale centralized wastewater treatment systems may no longer be the most viable option for urban water management in many countries. Decentralized wastewater treatment systems, serving individual or small groups of properties, have shown an increasing trend worldwide. They allow for the recovery of nutrients and energy, save freshwater and help secure access to water in times of scarcity. It has been estimated that the investment costs for these treatment facilities represent only 20–50% of conventional treatment plants, with even lower operation and maintenance costs (in the range of 5–25% of conventional activated sludge treatment plants) Low-cost sewerage systems have become a method of choice for neighbor hoods of all income levels. They differ from those used in conventional sewer design and focus on the concept that solid-free sewage is conveyed in the system. These systems lend themselves to community management and are very well suited to extend and expand existing systems or to connect satellite communities to centralized systems. They have also been used in refugee settings. One drawback is that they are not suitable for storm water drainage. Ecosystems can be effective in terms of providing economical wastewater treatment services, provided that these ecosystems are healthy, the pollutant load (and types of contaminants) in the effluent is regulated and the ecosystem’s pollution assimilation capacity is not exceeded.

3. Using Wastewater as an Alternative Source of Water

The use of untreated or diluted wastewater for irrigation has taken place for centuries. Reclaimed water also offers opportunities for a sustainable and reliable water supply for industries and municipalities, especially with a growing number of cities relying on more distant and/or alternative sources of water to meet increasing demand. In general, water reuse becomes more economically feasible if the point of reuse close to the point of production. Treating wastewater to a water quality standard acceptable by a user (i.e. ‘fit-for-purpose’ treatment) increases the potential for cost recovery. Wastewater use becomes all the more competitive when freshwater prices also reflect the opportunity cost of using freshwater and pollution charges reflect the cost of removing pollutants from wastewater flows. The planned use of treated and partially treated wastewater for ecosystem services can increase resource efficiency and provide benefits to ecosystems through reducing freshwater abstractions, recycling and reusing nutrients, allowing fisheries and other aquatic ecosystem to thrive by minimizing water pollution.

4. The Recovery of Useful by-Products

Wastewater’s vast potential as a source of resources, such as energy and nutrients, remains underexploited. Energy can be recovered in the form of biogas heating/cooling and electricity generation. Technologies exist for on-site energy recovery through sludge/bio solids treatment processes integrated in wastewater treatment plants allowing them to transition from major energy consumers to energy neutrality, or even to net energy producers. Energy recovery can also help facilities reduce operational costs and their carbon footprint, enabling increased revenue streams through carbon credits and carbon trading program. There are also opportunities for combined energy and nutrient recovery. Off-site energy recovery involves sludge incineration in centralized plants through thermal treatment processes. The development of technologies for recovering nitrogen and phosphorus from sewage or sewage sludge is advancing. Phosphorus recovery from on-site treatment facilities such as septic tanks and latrines can be technically and financially feasible by transforming waste into organic or organic mineral fertilizer. Moreover, faecal sludge presents a relatively lower risk of chemical contamination compared to swelt is likely that urine collection and use will become an increasingly important component of ecological wastewater management, as it contains 88% of the nitrogen and 66% of the phosphorus found in human waste – essential components for plant growth. With extractable mineral phosphorus resources predicted to become scarce or even exhausted over the next decades, its recovery from wastewater offers a realistic and viable alternative rage bio solids [5].

5. Pollutants of Industrial Waste Water

Industrial waste water pollutants can be categorized on the basis of sector of the industries. Each industry has its own category of pollutant. Here is a table given bellow:

Table-1. Pollutants and its Sources

Sector	Pollutant
Iron and steel	BOD, COD, oil, metals, acids, phenols and cyanide
Textile and leathers	BOD, solids, Sulphate and chromium
Pulp and paper	BOD, COD, solids, Organic compounds
Petrochemicals and refineries	BOD, COD, solids, oils, phenols and chromium
Chemicals	COD, organic compounds, heavy metals, SS and cyanide
Non-ferrous	Fluorine and SS
Microelectronics	COD and organic chemicals
Mining	SS, metals, acids and solids

5.1. Reasons of Waste Water Treatment [6]

Waste water create different organic compounds and inorganic compounds whose adverse effects on environments is harmful for all kinds of living beings. Here are some of the reasons why waste water is essential for treatment.

1. The decomposition of the organic materials confined in wastewater lead to the formation of large quantities of malodorous gases.
2. Raw wastewater (sewage) that contain a large amount of organic matter when discharged into a river / stream, will devour the dissolved oxygen for satisfying the Biochemical Oxygen Demand (BOD) of wastewater and thus deplete the dissolved oxygen of the stream, thereby causing fish kills and other undesirable effects.
3. Wastewater may also be contained with nutrients which can stimulate the growth of aquatic plants and algal blooms, thus leading to eutrophication of the lakes and streams.
4. Raw wastewater usually contains numerous pathogenic or disease causing microorganisms and toxic compounds, that dwell in the human intestinal tract or may be present in certain industrial waste. These may pollute the land or the water body, where such sewage is disposed.

5.2. Factors Affecting the Waste Water Treatments

There are several factors affecting the waste water treatment. These factors deal with the management of the waste water treatment by humans. Here are some of the factors are listed below:

a) User opinions and satisfaction
b) Community management
c) Level of service
d) Financial status
e) Materials and equipment
f) Personnel
g) Monitoring and control of water treatment

5.3. User Opinions and Satisfaction

The opinions of the user indirectly affect the performance of the water treatment. The water quality such as color, odor gives a bad impact to the users which results in the report to the water management controller. The waste water management control will try to solve the problem [6].

5.4. Community Management

Management community works to ensure the quality of water and manages the water treatment. The water treatment plant needs to be monitored as it needs machine and automatic run. A schedule of maintenance is prepared to supervise the performance of water treatment plant. The operator must be full time working for controlling and operating the water treatment plant [6].

5.5. Level of Service

The physical, chemical and biological content of water defines the quality of water. Water quality strategies give basic scientific information about water quality parameters and ecologically relevant toxicological threshold values to protect specific water uses. Water Treatment plant supply a water quality through the multi-level of process. This involves reservoir, disinfection, coagulation, flocculation, sedimentation and filtration. The reservoir can hold up to nine billion gallons of water. The disinfection process is to add up chlorine dioxide to kill bacteria and microorganisms in the water. The coagulation process is Ferric chloride and cationic polymer are quickly added and mixed into the water to begin the process of removing dirt and particles. Flocculation process is gentle mixing of the ferric chloride and polymer in the water causes dirt particles to stick together and become heavy, forming rust-colored "floc" clumps. The heavy, sticky floc clumps settle to the bottom of the basins, where they are vacuumed up by the traveling bridge. The remaining water flows over an end baffle, and then moves to the filters through sedimentation process. The water passes down through filters (layers of anthracite coal, sand and gravel) which trap and remove the remaining particles. Chlorine and ammonia are added for disinfection in the distribution system at the filtration process [6].

5.6. Financial Status

The treatment process constitutes of a big amount of money for the running of the machines and maintenance of the machines. The water treatment involves a lot of expenditure to operate it. Because of this reason, the government has allocated a lot of money to enable the water treatment well function. Thus, the user will get the benefit from this investment and can use the water safely. The expenditure spend is too ensure that the water treatment plant can perform well and produce quality water [6].

5.7. Materials and Equipment

The machinery and equipment use are suitable for processing the water, so that it can be use as drinking, farming, and industry. The machinery can be used for a long- term use and using a new technology to give a better performance towards water production [6].

5.8. Personnel

Performance of the technician or staff availability and training is also one of the factors of the waste water treatments. Plant operators need mechanical aptitude and should be competent in basic mathematics, chemistry, and biology. They must have the ability to apply data to formulas of treatment requirements, flow levels and concentration levels. Emergences also can be caused by conditions inside a plant, such as chlorine gas outflows or oxygen deficiencies. To deal with with these conditions, operators are trained in emergency management response using special safety equipment and procedures to safeguard public health and the facility [6].

5.9. Monitoring and Control of Waste Water Treatment [6]

Treatment methods require proper monitoring and control by manual methods or by continuous systems employing automatic instrumentation (Adapted from Water and Wastewater Treatment Plant Operators and Monitoring and control of water treatment). Described the conceptualization of the onsite water differentiable treatment system in two category, centralized water management systems and decentralized water management systems. Some of the value added benefits obtained through proper monitoring of a water treatment program include:

1. Reduced risks associated, with chemical underfeed or overfeed;
2. Continuing compliance with environmental regulations;
3. Improved quality of plant operation;
4 .Increased water and energy savings; and
5 .Improved plant production

On the other hand, the treatment results achieved in practice by the decentralized water wastewater management systems are not satisfactory when the IPP-relevant criteria (low consumption of resources, long-lasting technology, and advance treatment requirements) are used as a measure [6]. There are three major concerns

a) The effluent quality is mostly low and rarely allows safe reuse of water.
b) Treatment plants are not properly operated.
c) Treatment plants are difficult to supervise and control by water authorities.

5.10. Physical Method of Waste Water Treatment

The purpose of industrial water treatment is to deduct unwanted pollutants from water. There are many different methods of water treatment; these include biological processes, physical equipment, and chemical treatment. Physical water treatment generally consists of filtration techniques that involve the use of screens, sand filtration or cross flow filtration membranes.

6. Greensand Filtration

Glauconite is a mineral referred to as green sand and is used in greensand filtration. It is an efficient filtration medium for the removal of dissolved iron, hydrogen sulphide, and manganese from water. Glauconite when coated with manganese oxide, which causes soluble iron, manganese and hydrogen sulfide gas to bond with oxygen. Bonding with oxygen causes the previously dissolved elements to precipitate and become embedded in the greensand filter [7].

7. Ulti Media Filtration (MMF)

Multimedia filtration is a recent physical water treatment technique which uses at least three different layers of filtration media, typically anthracite, sand and garnet, to filter water. This filter preparation allows for larger particulates to be trapped at the top of the filter while smaller particulates are trapped deeper in the media. Suspended solids, including: clay, algae, silt, rust, and other organic matter are removed as the water passes through each layer of media. This filtration method is capable of removing particles from 10 to 25 microns in size. Multi-media filtration does not remove viruses, bacteria or smaller protozoans [7].

8. Microfiltration

Unlike greensand and multimedia filters, microfiltration uses a barrier membrane to filter very small suspended solids from water. Microfiltration membranes are usually capable of removing contaminants ranging from 0.1 to 10 microns in size. This form of physical water treatment is ideal for removing suspended solids, algae and protozoans from water but does not generally remove bacteria and viruses. Microfiltration does not remove dissolved contaminants from water [7].

9. Ultrafiltration

Ultrafiltration is a physical water filtration process that uses pressure to separate solids from water through a barrier membrane. This filtration process is capable of removing suspended solids, bacteria and certain viruses ranging from 0.005 to 0.01 micron in size, and is sometimes used as a pretreatment method upstream of reverse osmosis. Ultrafiltration cannot remove dissolved solids [8].

10. Nanofiltration

Nanofiltration mechanism is similar to ultrafiltration, but utilizes a semipermeable membrane with an even smaller pore size. Nanofilters are capable of removing bacteria, viruses and divalent and multivalent ions (e.g. calcium, magnesium). It works as a barrier membrane capable of removing particles ranging from 0.005 to 0.001 micron in size, and also acts as a semi-permeable membrane capable of removing ions. Due to its ability to remove divalent ions such as calcium it is sometimes referred to as the "softening membrane". Learn more about nanofiltration for industrial water treatment [8].

11. Reverse Osmosis

Reverse osmosis is one of the most common physical water treatment methods engaged in industrial water treatment. Reverse osmosis, also known as RO, filters contaminants out of water using applied pressure to force water through a semipermeable membrane. RO is proficient of removing impurities such as dissolved ions (e.g., sodium), bacteria, viruses, and other contaminants ranging from 0.005 to 0.0001 micron in size [9].

11.1. Wastewater Treatment through Membrane Technology

Membrane filtration separates and concentrates dissolved and undissolved elements from wastewater. This separation is performed under pressure. Due to its specific pore size, the membrane retains particles and molecules of a certain size. Different methods of membrane filtration are used for water purification, wastewater treatment, process water recycling, and the collection of recyclables in the recovery of valuable substances [9].

11.2. Wastewater Treatment through Flotation

Flotation removes dispersed or suspended substances from fluids by means of very fine gas bubbles that transport the substances to the surface, and subsequently, bubbles and substances are removed with a clearing device. In wastewater treatment, the flotation processes are used to separate oils, fats and finely suspended solids and particles. The smaller the microbubbles, the better the accumalation of particles or droplets function. To this end, wastewa-ter technology often uses Dis-solved Air Flotation (DAF), a method proven to be economically efficient. In addition, auxiliary agents such as collectors, frothers, controllers and pushers support flotation processes [9].

11.3. Solids Separation through Sedimentation

Sedimentation uses gravity to separate solid particles in sedimentation tanks. A sedimentation tank is a flat, nearly current free tank specifically designed for sedimentation processes. The solid particles settle on the bottom of the tank. Wastewater treatment uses sedimentation processes in different ways. In the preliminary cleaning tank, undissolved sub-stances settle and form primary sludge that is subsequently concentrated in the digestion tower where it is transformed anaerobically. The transformation process produces digested sludge and fermentation gas, which, in its cleaned form like biogas, is converted into electricity to cover energy demands. Aerobically formed sludge is additional to the digestion tower after it has been separated from the wastewater through sedimentation in the clarifier tank. In addition, sand traps and sludge collectors separate particles that are heavier than water [9].

11.4. Chemical Method of Waste Water Treatment

Generally the particles of different sizes are present in waste water.It is the size of particles present in wastewater determines the type of treatment that required. Particles can be classified based on their sizes as dissolved (< 0.08 µm), colloidal (0.08 - 1 µm), supra-colloidal (> 1 - 100 µm) and settle-able (> 100 µm). Physical treatments such settling, screening and DAF are capable of removing particles that are visible to the visible range eye. However, very fine particles of a colloidal nature (size < 1 µm) which have high stability are impossible to isolate by settling or by any other means of physical treatments. These fine particles such as inorganic matters and dissolved organics are the main pollutant and contribute significantly to the high BOD in the wastewater. These particles have negative electrostatic surface charges and due to the repulsive forces between them, they are unable to aggregate and subsequently settle [10]. It is not possible to isolate colloidal solids even by fine filters when they pass through any conventional filter. However, there is one way to separate these colloidal particles using chemical treatments. The separation can be achieved through addition of chemicals (called coagulants and flocculants) which enable these colloidal particles to form into flocs with settling properties [10].

11.5. Coagulation

Among other chemical waste water treatments coagulation is one of the essential process. Coagulation has been defined as the addition of a positively charged ion of metal salt or catalytic polyelectrolyte that results in particle destabilization and charge neutralization. Coagulation works with the colloid particles of size 10-7 to 10-14 cm in diameter. The colloid particles exhibit Brownian movement through the water; their surface is negatively charged so they repel one another, and they form a stable dispersed suspension. If colloid particles or ions of positive electric charge are added it neutralizes the electric negative charge [11].

11.6. Flocculation

Flocculation refers to the successful collision that occurs when destabilized particles are driven toward each other by the hydraulic shear force in the nonionic (neutrally charged). Chemical coagulation has been in practice for several decades to precipitate the soluble heavy metals present on the waste water, as hydroxides and facilitate their removal by physical separations through the sedimentation process [10].

11.7. Advanced Oxidation Process

Advanced Oxidation Processes (AOP) are effective methods that remove the non degradable organic pollutants by means of biological processes. They involve the production of extremely reactive oxygen species which are able to demolish a broad choice of organic compounds [12]. AOP are driven by an external energy sources such as electric power, ultraviolet radiation or solar light, so these processes are often more costly than traditional biological wastewater treatment. Furthermore, the AOP can be applied for the disinfection of water, air and for remediation of contaminated soils [13, 14]. Table 1 lists the advantages and disadvantages of different individual techniques. It is seen that a single, universally applicable end-of-pipe solution is impractical, and combination of different techniques is required to devise a technically and economically viable choice. In light of this, the researchers have put forward a range of hybrid decolorization techniques [15].

11.8. Combination of Electrochemical and Photochemical

In the electrochemical treatment, the oxidation is carried out by means of electrodes, where determined potential difference is applied. Based on this principle, many different processes were developed as direct and indirect electrochemical processes that include cathodic and anodic oxidation, electrocoagulation, electrodialysis, electromembrane, and electrochemical ion exchange. Sometimes the mixture of electrochemical technology and photocatalysis has been adopted for many unique advantages as for example, the chemical synergy process of photocatalysis and electrochemicals can give increased discoloration and the added benefit of the removal of chemical oxygen demand that may be derived from existence of the salt in solution, which otherwise is harmful to perform sole photo catalysis [16]. Conversely, electroFenton process requires no addition of chemicals other than the catalytic amount of Fe+2, that is produced from H2O2 in situ, thereby avoiding the transportation of the dangerous oxidant. With high pulsated voltage electrical discharge process, more oxidants such as H2O2 give rise to highly reactive free radical species by photo-dissociation of H2O2 and thus develops the overall process [16].

11.9. Membrane Bioreactors

A membrane bioreactor exhibits more improvement over conventional activated sludge treatment, and was shown to be promising in the color treatment of wastewater . For discoloration, a membrane bioreactor for is frequently introduced in conjunction with the charcoal amended digester that involves the current adsorption scheme of treatment. This is preceded by the aerobic membrane bioreactor that comprehends stable discoloration together with the elimination of high total organic carbon. Rarely the membrane bioreactors were used as major treatment process before the polishing of the nano filtration step or in the complicated treatments that include anaerobic/aerobic pretreatment before membrane bioreactor ozonation . The current literature includes an innovative approach of using the membrane separated fungus reactor which helps in the excellent degradation ability of white-mold [15].

12. Hybrid Biological Process

12.1. Biodegradation

The conventional pre or post treatment concepts includes the the design process containing individual components that are independent of each other. In contrast to this, a more innovative "integrated- process" approach was developed which combined the efficacy of the biological and other treatments that are synergistic in their effect . A typical example of this processes is the advanced of an activated sludge treatment where chemical oxidation was specifically designed to partially degrade recalcitrant contaminants to readily biodegradable intermediates. In the current years, the studies relating to the partial pre-oxidation of myriads of dye wastewater reported the involvement of all kinds of PDO. Some of these studies included the partial oxidation ozonation, H2O2 photocatalysis, photography -Fenton moist air oxidation combined with photocatalysis and ozonation/H2O2, photo-electrochemical process under oxidation, and water and supercritical electron beam bulk of treatment . These studies reported on the improvement of the biodegradability and the reduction of toxicity following PDO treatment without the biological reactor. However, the complete results were not obtained. The combined oxidation and subsequent biodegradation make it [15].

12.2. Physico-Chemical Treatment

As mentioned above, the literature is replete with examples of using the additional coagulation organic discoloration. The choice between the coagulation - biological or biological-coagulation system depends on the type and dosage of the coagulant, the amount of sludge, and the degree of inhibitory and nonbiodegradable substances in the wastewater . Coagulation before biological treatment may be advantageous for the alkaline wastewater but after biological treatment, the ferrous sulfate treatment cannot be used as the pH becomes close to neutral. On the contrary, the dose of coagulants and the amount of the bio-sludge after chemical treatment are smaller compared to those of the coagulation followed with biological treatment .Besides coagulation, a variety of other treatments can be combined with a biological treatment. Very often certain physicochemical process is located before and /or after AOP. The biological method is either applied as a penultimate or the last treatment unit. Given the abundance of the bio resistant toxic substances in wastewater dyes, the physico-chemical pre-treatment and advanced oxidation before biological treatment seems to be a rational choice. The choice between the physico-chemical and oxidative pretreatment depends on the specific wastewater and, usually bright-stream separation would facilitate the application of appropriate treatment or different streams [15].

12.3. Adsorption with Biodegradation

Adsorption with biodegradation: Conventional biological treatments have limited effectiveness in the treatment of rebellious textiles wastewater that is mostly composed of recalcitrant chemicals. Due to this reason the textile dyes, various adsorbents and chemicals that predominantly include the activated carbon were directly added to the activated sewage systems in some studies .The fact that the additional removal of soluble organic substances (chemical oxygen demand and and total organic carbon), in such a system compared to the conventional system cannot explain the likely contribution of adsorbent as it was predicted that the adsorption isotherms assume a synergistic relationship between the activated carbon and microorganism . Enhanced biodegradation was attributed to the ability of the adsorbent that acts as a modulator by immediately adsorbing the high concentrations of toxic substances, thereby managing the free concentration of toxic substances. This provides an augmented environment for the microbial metabolism that takes place at the liquid-solid surface onto which the microbial cells, enzymes, organic materials and oxygen are adsorbed . The main step in dye removal for activated carbon amended biological process is microbial degradation, which is higher than the adsorption on both activated carbon as well as on biomass[15]. Here are some of the advantages and disadvantages of the some waste water treatments

Table-2. Advantages and disadvantages of various waste water treatments

Process	Advantages	Disadvantages	References
Biologocal	Cost-competitive option. Direct, disperse and basic dyes have high level of adsorption on to activated sludge.	Dyes are generally toxic and very resistant to bio degradation. Acid and reactive dyes are highly watersoluble and have poor adsorption on to sludge	[17]
Coagulation	Economically feasible; satisfactory removal of disperse, sulphur and vat dyes.	Removal is pH dependent; produces large quantity of sludge. May not remove highly soluble dyes; unsatisfactory result with azo, reactive, acid and basic dyes.	[18-21]
Activated Carbon adsorption	Good removal of wide variety of dyes, namely, azo, reactive and acid dyes; especially suitable for basic dye	Removal is pH dependent; unsatisfactory result for disperse, sulfur and vat dyes. Regeneration is expensive and involves adsorbent loss; necessitates costly disposal**.**	[22]
Ion exchange	Adsorbent can be regenerated without loss, dye recovery conceptually possible.	recovery conceptually possible. Ion exchange resins are dye-specific; regeneration is expensive; large-scale dye recovery cost-prohibitive.	[23]
Chemical oxidation	Initiates and accelerates azo-bond cleavage.	Thermodynamic and kinetic limitations along with secondary pollution are associated with different oxidants. Not applicable for disperse dyes. Negligible mineralization possible, release of aromatic	[24]

		amines and additional contamination with chlorine (in case of NaOCl) is suspected.	
Advanced oxidation process	Generate a large number of highly reactive free radicals and by far surpass the conventional oxidants in decolorization	AOPs in general may produce further undesirable toxic byproducts and complete mineralization may not be possible. Presences of radical scavengers reduce efficiency of the processes some of which are pH dependent. Cost-prohibitive at their present stage of development.	[24]
UV/O3	Applied in gaseous state, no alteration of volume. Good removal of almost all types of dyes; especially suitable for reactive dyes. Involves no sludge formation, necessitates short reaction times.	Removal is pH dependent (neutral to slightly alkaline); poor removal of disperse dyes. Problematic handling, impose additional loading of water with ozone. Negligible or no COD removal. High cost of generation coupled with very short half-life and gas-liquid mass transfer limitation	[25-27]
UV/H2O2	Involves no sludge formation, necessitates short reaction times and COD reductionmay be possible to some extent.	Not applicable for all dye types, requires separation of suspended solid and suffers from UV light penetration limitation. Lower pH required to nullify effect of radical scavengers.	[28]
Fenton's reagent	Effective decolorization of both soluble and insoluble dyes; applicable even with high suspended solid concentration. Simple equipment and easy implementation. Reduction of COD (except with reactive dyes) possible.	Effective within narrow pH range of <3.5; and involves sludge generation. Comparatively longer reaction time require.	[29]
Photocatalysis	No sludge production, considerable reduction of COD, potential of solar light utilization.	Light penetration limitation, fouling of catalysts, and problem of fine catalyst separation from the treated liquid (slurry reactors)	[30]
Electrochemical	Effective decolorization of soluble/insoluble dyes; reduction of COD possible. Not affected by presence of salt in wastewate.	Sludge production and secondary pollution (from chlorinated organics, heavy metals) are associated with electrocoagulation and indirect oxidation, respectively. Direct anodic oxidation requires further development for industrial acceptance. High cost of electricity is an impediment. Efficiency depends on dye nature	[31]

12.4. Adsorption

Adsorption techniques are specific on the use of bleaching of dyes in industrial effluents. The activated carbon, either in the powder or granular form is broadly used adsorbent due to its extensive surface micro porous structure, high adsorption capacity and high surface reactivity. Its efficiency is observed in the absorption of cationic, mordant and acid dyes and to a lesser extent dispersed, direct, vat, pigment and reactive dyes. The use of carbon adsorption for decolorization of the crude wastewater is impractical as a consequence of the competition between the colored molecules, and other organic/ inorganic compounds. Hence, its use is suggested as an improving step or used at the end of an emergency unit treatment stage to meet the discharge color duration. The weight loss is expected during its expensive onsite regeneration and hampers its widespread use thus use of non-conventional, economical sources as precursors for activated carbon has been proposed to achieve the cost-effectiveness in the application. As previously stated adsorption is a non-destructive method in which there is only the change in the phase of the detached impurities and, therefore imposes further problems in the form of sludge. On the contrary, some catalytic oxidation /reduction systems seem to be more effectively focused on the treatment of the small volume dyes. So it seems attractive to combine other adsorption process in a system where the contaminants are pre-concentrated on the absorbent, and then separated from the water. The thus separated contaminants can subsequently be mineralized (example wet air oxidation) or degraded to a certain extent (for example azo bond reduction with bisulfite mediated borohydride to regenerate the adsorbent and re-use). In this method, an economic process can be developed linking two processing techniques that can eliminate their inherent disadvantages. The application of partial degradation to regenerate the adsorbent leaves behind a small amount of wastewater to treat. Again, this can be easily taken care of by the application of some AOP. Adsorption simultaneously with ozonation, UV-H2O2 or microwave has induced oxidation. The mutual reported improvements such as catalysis of AOP yield by adsorbent and simultaneous regeneration of adsorbent. A rather complicated method involving solvent extraction and catalytic oxidation has been documented in the literature. This method involves dye extraction by means of an economical solvent, followed by recovery with dye chemical stripping [15].

Combination of photochemical and electrochemical process: In the electrochemical treatment, the oxidation is carried out by means of electrodes, where determined potential difference is applied. Based on this principle, many different processes were developed as direct and indirect electrochemical processes that include cathodic and anodic oxidation, electrocoagulation, electrodialysis, electro membrane, and electrochemical ion exchange. Sometimes the combination of electrochemical technology and photocatalysis has been adopted for unique advantages. For example, the chemical synergy process of photocatalysis and electro chemicals can give increased discoloration and the added benefit of the removal of chemical oxygen demand that may be derived from presence of the salt in solution, which is harmful to perform sole photo catalysis. Conversely, electro Fenton process requires no addition of chemicals other than the catalytic amount of Fe+2, that is produced from H2O2 in situ, thereby avoiding the transportation of the dangerous oxidant. With high pulsed voltage electrical discharge process, more oxidants such as H2O2 give rise to highly reactive free radical species by photo-dissociation of H2O2 and thus improve the overall process [15].

12.5. Combination with Membrane Technology

Membrane separation gives the possibilities of either the concentration of the dyes and adjuvants and producing purified water, or the removal of the dye and allowing the re-use of water along with extra chemicals, or even the realization of the recovery of the substantial part of the dye, admixtures and water all together. This recovery/reuse practice reduces many folds the recurring cost for the treatment of was increasing. Accordingly, water and/or electrolytic recovery of dye bath effluent have become the focus of contemporary literature. However, the production of concentrated sludge and the occurrence of frequent membrane fouling that involves expensive membrane replacement hinder the widespread use of this technology. Two different trends are so evident among the reported studies that link the membrane separation and other technologies. Some studies focused on the reduction of the membrane concentrated disposal problem, while others concentrated on the full-hybrid systems, which might eliminate the limitations of the membrane technology, and/or that of the counterpart technologies [15].

12.6. Treatment of Waste Water with Low Cost Zeolite and Bentonite

In this treatment natural zeolite and bentonite were used to treat Cobalt and Nickel from waste water. Bentonite showed better efficiency than Zeolite. The mixture of Z/B shows more efficiency than zeolite in the removal of cobalt and nickel. The high value of correlation factor indicates the adsorption onto Z/B mixture is more accurately described by Freundlich isotherm. The adsorption process was described by pseudo second order reaction [32].

12.7. Novel Biofiltration Method for the Treatment of Industrial Waste Water

Heavy metals are mostly toxic and carcinogenic when they are discharged into the wastewater from industries creating threat to humans and living beings. The heavy metals being mixed with the water bodies polluting the pure water bodies. Among the other conventional process biofiltration has shown its performance. Biofiltration is capable of removing heavy metals up to ppb level and is cheaper, application of this technique for the treatment of waste water of the industries like chemicals, fertilizers, textiles, paper and pulp, dyes and pigments, pharmaceuticals etc. with help of this unit to meet the statutory mandate and to alleviate the threat of survival of high waste water treatment cost of these units. In short biofilters are having emerging applications in the removal of heavy metals from waste water [33].

12.8. Removal of Heavy Metals Using Ion Exchange Method

By ion exchange method undesirable ions are replaced by others which don’t contribute to contamination of the environment. The method is technologically simple and enables efficient removal of even traces of impurities from solutions. Examples of selective removal of heavy metal ions by ion-exchange are presented. They include removal of Pb(II), Hg(II), Cd(II), Ni(II), V(IV,V), Cr(III,VI), Cu(II) and Zn(II) from water and industrial wastewaters by means various modern types of ion exchangers [34].

12.9. Removal of Mercury

Mercury is one of the most hazardous contaminant in natural environment because it spreads easily and will be accumulated in living organisms. In wastewaters, mercury occurs in the forms of metallic, dissociated molecules, Hg2þ and Hg22þ ions as well as complex ions. To remove mercury compounds mainly reduction, precipitation, extraction and ion ex-change methods are applied. In comparison to the other methods ion-exchange are technologically simple and enable efficient for the removal of even of traces from solutions. They are particularly useful when it is necessary to treat large volumes of diluted solutions. It is possible to remove Hg(II) ions from waters and industrial wastewaters on various types of ion exchanger e.g. strongly acidic cation exchangers, weakly and strongly basic anion exchangers as well as on selective ion exchangers of various. Many West European industries apply the selective ion exchanger Imac TMR (Akzo Zout) for selective removal of Hg(II) ions from technological solutions, mainly from electrolytic brines. Imac TMR is a styrenedivinylbenzene copolymer which has mainly functional thiol groups and a number of sulphonic groups and exhibits a macro porous structure. The-SH groups are characterized by very low acidity degree (PKa 10:8), their redox potential is +135 mV. Due to the presence of-SH groups, strong affinity of this cation exchanger for Hg(II) ions enables reactions of Hg(II) ions with mercaptans, thiophenols or hydrogen sulphide. Its capacity from Hg(II) ions is 240 g Hg dm^3 of ion exchanger. For comparison: using reduction methods it is possible to diminish the mercury content in wastewaters down to 1–3 ppm by precipitation of HgS, with hydrogen sulphide to 1 ppm and applying the ion exchanger Imac TMR to 0.5–5.0 PPB [34].

13. Conclusion

This paper is a review of variety of methods that may be executed in the treatment of wastewater. It is apparent that a variety of options are feasible for use in the developing world and even more apparent that many low-technology options can be mixed and matched for very high efficiencies. Natural treatment technologies are seeking attraction to a significant level of interest by environmental managers. Natural treatment technologies are considered viable because of their low capital costs, their ease of maintenance, their potentially longer life-cycles and their ability to recover a variety of resources. This paper analyses emergent issues and technological options related to the scale of collection and treatment systems of waste water.

Acknowledgments

The research work was supported by the The Ministry of Science and Technology, Government of the People's Republic of Bangladesh under the Special Allocation for Science and Technology Programme, Financial Year 2020-2021. The project title was: Analysis and Treatment of River Water Using Bio-based Polymeric Materials and Gamma Radiation for Radiological Applications, Group Serial No.445 EAS.

References

[1] Almeida, M. C., Butler, D., and Friedler, E., 1999. "At-source domestic wastewater quality." *Urban Water,* vol. 1, pp. 49-55.

[2] Touloumi, G., Pocock, S. J., Katsouyanni, K., and Trichopoulos, D., 1994. "Short-term effects of air pollution on daily mortality in Athens: a time-series analysis." *International Journal of Epidemiology,* vol. 23, pp. 957-967.

[3] Okoh, A. I., Odjadjare, E. E., Igbinosa, E. O., and Osode, A. N., 2007. "Wastewater treatment plants as a source of microbial pathogens in receiving watersheds." *African Journal of Biotechnology,* vol. 6, pp. 2932-2944.

[4] Gleick, P. H., 1998. "The human right to water." *Water Policy,* vol. 1, pp. 487-503.

[5] Remy, C. and Jekel, M., 2008. "Sustainable wastewater management: life cycle assessment of conventional and source-separating urban sanitation systems." *Water Science and Technology,* vol. 58, pp. 1555-1562.

[6] Omran, A., 2011. "Factors influencing water treatment management performance in Malaysia: a case study in Pulau Pinang." *Annals of the Faculty of Engineering Hunedoara,* vol. 9, p. 53.

[7] Brinck, W. L., Schliekelman, R. J., Bennett, D. L., Bell, C. R., and Markwood, I. M., 1978. "Radium-removal efficiencies in water-treatment processes." *Journal-American Water Works Association,* vol. 70, pp. 31-35.

[8] Li, Y. S., Yan, L., Xiang, C. B., and Hong, L. J., 2006. "Treatment of oily wastewater by organic–inorganic composite tubular ultrafiltration (UF) membranes." *Desalination,* vol. 196, pp. 76-83.

[9] Sonune, A. and Ghate, R., 2004. "Developments in wastewater treatment methods." *Desalination,* vol. 167, pp. 55-63.

[10] Sahu, O. P. and Chaudhari, P. K., 2013. "Review on chemical treatment of industrial waste water." *Journal of Applied Sciences and Environmental Management,* vol. 17, pp. 241-257.

[11] Bache, D. H., Johnson, C., Papavasilopoulos, E., Rasool, E., and McGilligan, F. J., 1999. "Sweep coagulation: structures, mechanisms and practice." *Journal of Water Supply: Research and Technology-Aqua,* vol. 48, pp. 201-210.

[12] Arslan, I., Balcioğlu, I. A., and Bahnemann, D. W., 2000. "Advanced chemical oxidation of reactive dyes in simulated dyehouse effluents by ferrioxalate-Fenton/UV-A and TiO2/UV-A processes." *Dyes and pigments,* vol. 47, pp. 207-218.

[13] Babel, S. and Kurniawan, T. A., 2003. "Low-cost adsorbents for heavy metals uptake from contaminated water: a review." *Journal of Hazardous Materials,* vol. 97, pp. 219-243.

[14] Asgher, M., Azim, N., and Bhatti, H. N., 2009. "Decolorization of practical textile industry effluents by white rot fungus Coriolus versicolor IBL-04." *Biochemical Engineering Journal,* vol. 47, pp. 61-65.

[15] Shah, M. P., 2016. "Industrial wastewater treatment: A challenging task in the industrial waste management." *Advances in Recycling and Waste Management,* vol. 2, p. 115.

[16] Zhang, S., Wang, D., Quan, X., Zhou, L., and Zhang, X., 2013. "Multi-walled carbon nanotubes immobilized on zero-valent iron plates (Fe0-CNTs) for catalytic ozonation of methylene blue as model compound in a bubbling reactor." *Separation and Purification Technology,* vol. 116, pp. 351-359.

[17] Bandara, J., Morrison, C., Kiwi, J., Pulgarin, C., and Peringer, P., 1996. "Degradation/decoloration of concentrated solutions of Orange II. Kinetics and quantum yield for sunlight induced reactions via Fenton type reagents." *Journal of Photochemistry and Photobiology A: Chemistry,* vol. 99, pp. 57-66.

[18] Borchate, S. S., Kullkarni, G. S., Kore, V. S., and Kore, S. V., 2014. "A review on applications of coagulation-flocculation and ballast flocculation for water and wastewater." *International Journal of Innovations in Engineering and Technology,* vol. 4, pp. 216-222.

[19] Baughman, G. L. and Weber, E. J., 1994. "Transformation of dyes and related compounds in anoxic sediment: kinetics and products." *Environmental Science and Technology,* vol. 28, pp. 267-276.

[20] Beydilli, M. I., Pavlostathis, S. G., and Tincher, W. C., 1998. "Decolorization and toxicity screening of selected reactive azo dyes under methanogenic conditions." *Water Science and Technology,* vol. 38, pp. 225-232.

[21] Blümel, S. and Stolz, A., 2003. "Cloning and characterization of the gene coding for the aerobic azoreductase from Pigmentiphaga kullae K24." *Applied Microbiology and Biotechnology,* vol. 62, pp. 186-190.

[22] Böhmer, U., Kirsten, C., Bley, T., and Noack, M., 2010. "White-rot fungi combined with lignite granules and lignitic xylite to decolorize textile industry wastewater." *Engineering in Life Sciences,* vol. 10, pp. 26-34.

[23] Bragger, J. L., Lloyd, A. W., Soozandehfar, S. H., Bloomfield, S. F., Marriott, C., and Martin, G. P., 1997. "Investigations into the azo reducing activity of a common colonic microorganism." *International Journal of Pharmaceutics,* vol. 157, pp. 61-71.

[24] Brown, J. P., 1981. "Reduction of polymeric azo and nitro dyes by intestinal bacteria." *Appl. Environ. Microbiol.,* vol. 41, pp. 1283-1286.

[25] Casieri, L., Varese, G. C., Anastasi, A., Prigione, V., Svobodova, K., Marchisio, V. F., and Novotný, Č., 2008. "Decolorization and detoxication of reactive industrial dyes by immobilized fungi Trametes pubescens and Pleurotus ostreatus." *Folia Microbiologica,* vol. 53, p. 44.

[26] Singh, P. K. and Singh, R. L., 2017. "Bio-removal of azo dyes: A review." *International Journal of Applied Sciences and Biotechnology*, vol. 5, pp. 108-126.

[27] Chen, H., Wang, R. F., and Cerniglia, C. E., 2004. "Molecular cloning, overexpression, purification, and characterization of an aerobic FMN-dependent azoreductase from Enterococcus faecalis." *Protein Expression and Purification,* vol. 34, pp. 302-310.

[28] Chivukula, M. and Renganathan, V., 1995. "Phenolic azo dye oxidation by laccase from Pyricularia oryzae." *Appl. Environ. Microbiol.,* vol. 61, pp. 4374-4377.

[29] Chung, K. T. and Stevens, S. E., 1993. "Degradation azo dyes by environmental microorganisms and helminths." *Environmental Toxicology and Chemistry,* vol. 12, pp. 2121-2132.

[30] Chung, K. T., Stevens, S. E., and Cerniglia, C. E., 1992. "The reduction of azo dyes by the intestinal microflora." *Critical Reviews in Microbiology,* vol. 18, pp. 175-190.

[31] Claus, H., Faber, G., and König, H., 2002. "Redox-mediated decolorization of synthetic dyes by fungal laccases." *Applied Microbiology and Biotechnology,* vol. 59, pp. 672-678.

[32] Al Dwairi, R. and Al-Rawajfeh, A., 2012. "Removal of cobalt and nickel from wastewater by using Jordan low-cost zeolite and bentonite." *Journal of the University of Chemical Technology and Metallurgy,* vol. 47, pp. 69-76.

[33] Srivastava, N. K. and Majumder, C. B., 2008. "Novel biofiltration methods for the treatment of heavy metals from industrial wastewater." *Journal of Hazardous Materials,* vol. 151, pp. 1-8.

[34] Dąbrowski, A., Hubicki, Z., Podkościelny, P., and Robens, E., 2004. "Selective removal of the heavy metal ions from waters and industrial wastewaters by ion-exchange method." *Chemosphere,* vol. 56, pp. 91-106.