International Journal of Humanities Social Science and Management (IJHSSM)
Volume 3, Issue 4, Jul.-Aug., 2023, pp: 34-42 www.ijhssm.org

Bioremediation of paper industry waste from mill effluent:- a review

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Date of Submission: 01-07-2023 Date of Acceptance: 10-07-2023

Abstract:
-The annual production of nearly 1.6 billion tons of waste presents numerous health and environmental risks, so effective programs for waste disposal and management require immediate attention. Reduced production of toxic residues and the release of nutrients that have been trapped during mineralization make biodegradation and bioremediation environmentally friendly options. The so-called "waste substances" have a lot of energy, a lot of which is wasted because they don't get used.Currently, the pulp and paper industry's effluents contain approximately 240-250 chemicals and the 50-60 m3 of water required to produce a ton of paper. These chemicals are produced at various stages of the papermaking process. The mash and paper industry is ordinarily connected with contamination issues connected with high Body, COD, harmfulness, AOX, variety, suspended solids, lignin and its subsidiaries and chlorinated compounds. Despite the fact that a number of researches have looked into ways to get rid of COD, BOD, color, etc. of mash and paper effluents, the issue actually continues to happen.Utilizing bioremediation techniques to solve issues with the dumping of paper waste has the potential to lessen environmental pollution.

I. -Introduction:-

Utilizing biological systems to catalyze the degradation or transformation of numerous toxic chemicals into less harmful forms, bioremediation is a pollution control technique. Various industrial effluents, including sewage water, tannery, distillery, and paper and pulp industry effluents, can be treated with bioremediation [1].The pulp and paper industry is now one of the world's most important industrial sectors thanks to its economic benefits. Still presently, mash and paper plants are confronting difficulties with the energy productivity instruments and the executives of the noteworthy toxins, taking into account the ecological criticisms and getting through lawful prerequisites [2].In general, the pulp and paper industry has been regarded as a significant polluter of the environment and a major consumer of natural resources (wood, water, and energy from fossil fuels, for example). After oil, cement, leather, textile, and steel industries, the pulp and paper industry is the sixth largest polluter, releasing a variety of gaseous, liquid, and solid wastes into the environment. The highwater consumption of the pulp and paper industry does not limit the environmental issues it causes [3].

The pulp and paper industry typically produces a lot of wastewater, which must be properly treated before being released into the environment; Otherwise, it is a significant issue for the economy and the environment. The lingering dark brown color caused by lignin and its derivatives, like chlorolignin , in the pulp bleaching process's discharged effluent is a significant issue[4].The presence of chromophoric organic compounds with high molecular weights, which are harmful to human health as a whole, is one particular issue with pulp mill effluent [5].If left untreated, the effluent has a high Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), chlorinated compounds measured as adsorbable organic halides (AOX), suspended solids primarily consisting of fibers, fatty acids, tannins, resin acids, lignin and its derivatives, sulfur and sulfur compounds, etc., which can cause significant damage to the receiving water [6].Among other things, suspended solids, biological oxygen demand (BOD), dirt, grit, and fibers are produced during the preparation of wood, the source of papermaking fiber. Resins, fatty acids, color, BOD content, chemical oxygen demand (COD) content, adsorbable organohalogens, and volatile organic carbons (terpenes, alcohols, phenols, methanol, acetone, chloroform, among others) can all be found in the "Black Liquor" (BL) that is produced by digesters in kraft mills [7].

Process stages	Wastewater (v)	Pollution load	Effluent contents
Raw material preparation	Low	Low	Suspended solids including bark particles, fiber pigments, dirt, grit, BOD and COD
Pulping	Low	High	Color, bark particles, soluble wood materials, resin acids, fatty acids, AOX, VOCs, BOD, COD and dissolved inorganics
Bleaching	High	High	Dissolved lignin, color, COD, carbohydrate, inorganic chlorines, AOX, EOX, VOCs, chlorophenols and halogenated hydrocarbons
Paper-making	Depends on the extent of the recycling effluents	Low	Particulate wastes, organic and inorganic compounds, COD and BOD

Table 1: Major pollutants released from paper and pulp making process[8].

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Soil pollution and contamination of surface and ground water are the primary effects of improper waste disposal. Numerous pathogens, vectors, pests, and germs thrive in these waste disposal facilities. Toxic gas emissions, air pollution caused by waste combustion, leachates, and methane released by waste matter decomposition, among other things are the most prevalent precarious effects. Additional health risks are presented by landfills that are close to populated areas [9].

The industry is being forced to treat effluents to the required compliance level before discharging them into the environment as a result of strict regulations and public awareness of the fate of these pollutants [10].

Pulp and paper mill effluents- A major threat

One of the world's largest and most polluting industries is the pulp and paper industry. In Orth A Meri Ca, it ranks third in terms of polluting industries. In 1987, the world's population consumed more than 214 million tons of paper and board products, and all estimates indicate that this number will continue to rise [11].

There are approximately 500 kraft mills worldwide, in addition to many thousands of other types of pulp and paper mills. At the moment, the installed capacity of the Indian pulp and paper industry is approximately 3.0 million tons per year [12].

Effect of pulp pollution :-

Water pollution:-

-Pulp mill effluents have the potential to seriously harm habitat mills, decrease the amount of water required for farming, and alter water temperature—a crucial environmental factor for farming. The ecosystem around the mill continues to suffer as a result of mill waste. Lignin and its derivatives give the water a offensive color, which is not only unattractive but also prevents the stream's natural process of photosynthesis from taking place because they absorb sunlight. Because of this, the growth of primary, secondary, and tertiary consumers, as well as the aquatic ecosystem as a whole, is negatively impacted [13].Ebeling discovered negative effects on the environment caused by pulp mill discharges as early as the 1930s[14].The use of elemental chlorine in pulp bleaching processes was found to be the cause of chlorinated organic compounds being isolated in pulp mill effluents and receiving environments in early 1980s studies [15].More than 260 chemicals have been found in the effluents of paper and pulp mills that are produced at various stages of the papermaking process [16].

The aquatic flora and fauna will suffer as a result of the tannins in the wastewater from the paper mill, which tend to absorb more light and heat and retain less oxygen than untreated water [17].It was laid out that consolidated tannins from tidy bark are harmful, no exclusively to methanogens at fixations present in the paper factory wastewater yet in addition to sea-going organic entities, similar to fish and change their social reaction, improvement and development, influence on insusceptible framework, influence on compounds and regenerative [18][19].

In the 1990s, it became clear that these effluents were by nature complex and variable, both temporally and spatially, and that it would be difficult to separate toxic compounds from effluent [20].The color remains in the receiving body for a considerable distance when wastewater from pulp and paper mills is discharged untreated or partially treated[21]

Air pollution:-
-Chlorinated phenols, polycyclic aromatic hydrocarbons (PAHs), and volatile organic compounds (VOCs) are hormone disrupting and carcinogenic chemicals found in pulp mill air discharges [22].
Advance treatment of paper and pulp mill effluents:-

-Utilizing the technology that is available, a variety of internal process modifications and management measures can be used to reduce the amount of effluent produced by the pulp and paper industry [23].An internal process change at Irving Pulp and Paper Limited was found to have reduced the effluent's BOD by nearly 60% [24].
-By conventional and non-conventional means like sedimentation, flotation, screening, adsorption, coagulation, oxidation, ozonation, electrolysis, reverse osmosis, ultra-filtration and nano-filtration technologies, the replacement of chlorine by hypochlorite, sorption on hypo and alum-sludge, activated carbon, and all phenolic compounds, physicochemical treatment processes remove suspended solids, colloidal particles, floating things, colors, and toxic [25][26][27].

Waste management strategies:-

:-Waste to energy program
A rapidly developing waste management strategy is the waste to energy transformation strategy, in which waste material is used to generate energy. Many nations are quickly adopting this strategy [28].The global market for waste to energy was valued at approximately $25.32 billion in 2013, a significant increase over the years [29].The majority of landfill gas (LFG) is made up of 50 percent each of CO2 and CH4 from the decomposition of organic waste in landfills. Methane has a 25 percent greater capacity to cause global warming than CO2, making it an environmentally friendly method. Thermal kilns, boilers, infrared heaters, sludge dryers, forgers, electricity generation, leachate evaporation, blacksmithing forges, and other applications typically make use of LFG [30].

:- Biodegradation of paper wastes:-

-Bacteria have the ability to break down cellulose, so they can effectively be used to break down waste paper [31].
-1 gram of paper waste was incubated at 35°C for 90 days with soil-isolated bacterial species, E. coli, Pseudomonas florescence, and Bacillus subtillis , resulting in a clearance zone of approximately 13.3 mm in diameter, with Pseudomonas florescence hydrolyzing the paper most actively [32].Consortia of microbial and fungal organisms like Bacillus cereus, A. niger, and others can actively break down paper waste [33].

:-Biological treatment(microbes in bioremediation):-

-Utilizing microorganisms like fungi, bacteria, algae, and enzymes as a single step treatment or in conjunction with other physical and/or chemical methods are examples of biological treatment.[34].Bioremediation is a method for reducing pollution that makes use of biological systems to accelerate the breakdown or transformation of a variety of harmful chemicals into less harmful forms [35].

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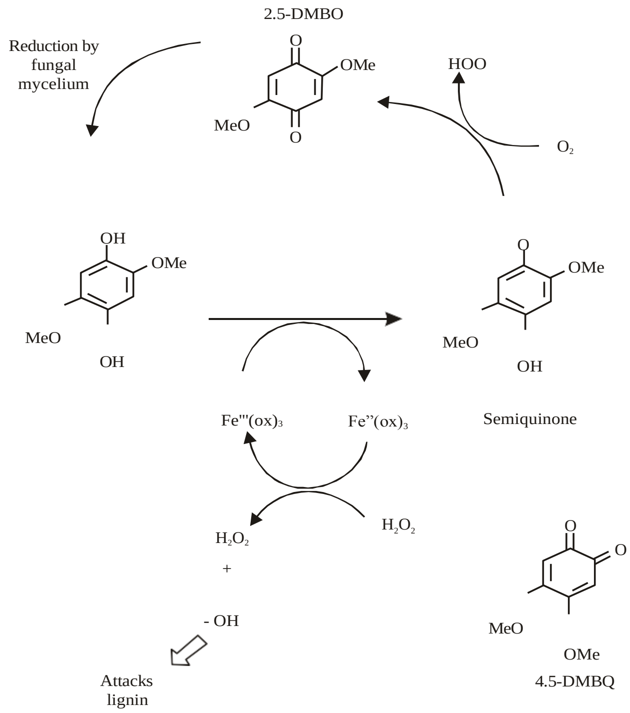

Fig. 1: Scheme of the fenton redox cycle found in brown-rot fungi[35].

However, conventional biological processes have not been able to effectively remove colour and recalcitrant compounds from wastewater from paper and pulp. Utilizing biological systems to catalyze the degradation or transformation of various toxic chemicals into less harmful forms, bioremediation is a pollution control technology. As a result, various industrial effluents, such as pulp and paper mill effluent, are treated through bioremediation [35][36][37].

Remediation with bacteria :-

- Although many bacteria can decompose monomeric lignin substructure models, only a few strains are able to attack lignin derivatives obtained from various pulping processes, according to observations [38][39].
- Resin acids are tricyclic diterpenes that are naturally present in the resin of tree wood and bark. During pulping operations, these acids are transferred to process waters. They are toxic to fish at concentrations of 200-800 mg LG1 in wood processing wastewater and are considered to be willingly biodegradable. They are weak hydrophobic acids [40][41]. The isolated bacteria, such as Citrobacter spp. and Pseudomonas putida and the genus Enterobacter can decolorize effluent up to 97 percent, reduce BOD, COD, phenolics, and sulfide up to 96.63, 96.80, 96.92, and 96.67 percent, respectively, within 24 hours of growth, and remove heavy metals up to 82-99.80 percent [42][43].
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Decolourization with bacteria :-

- Under aerobic conditions, Pseudomonas aeruginosa bacterial cultures can reduce the colour of Kraft mill effluent by 26-54% or more [45]. In a continuous reactor, the degradation of black liquor from a Kraft pulp and paper mill was investigated using two strains of bacteria: Pseudomonas putida and Acienetobacter calcoaceticus .They were able to effectively remove 70-80% of COD and lignin, and their colour removal efficiency was approximately 85 o/c in eight days [46].
- Resin acids, a class of diterpenoid carboxylic acids that are typically found in softwoods, are found in a lot of pulp mill effluents and are harmful to fish in the receiving waters. They are thought to be simple to break down in the body.

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However, it has been demonstrated that the biological treatment systems that remove them differ.

Recent research suggested that natural acids and transformation products' residuals could build up in sediments and cause acute and chronic fish toxicity.

Additionally, it has been demonstrated that a number of res in ac id biotransformation compounds bioaccumulate and are more biodegradable than the original material.

Fungi that live in wood have been shown to lower the amount of resin in wood, but there is no conclusive proof that fungi can completely break down these compounds. Dehydroabietic or isoimaric acids, on the other hand, have recently been identified as the sole carbon source for a number of bacterial isolates2X [47]. It appears that lignin is not biodegraded anaerobically. Even in aerobic conditions, bacterial degradation is neither rapid nor extensive. Streptomyces etonii and Streptomyces viridosporus have not been the most extensively studied for their ability to degrade lignin [48].

---**Factors effect on degradations processes** :-

- The pH of the effluent, an additional carbon source (as a nutrient), agitation, the size of the inoculum, and the colour removal mechanism all affect how selective bacteria degrade the organic and inorganic loads in the effluent [49].

--Effect of pH on the colour and turbidity characteristics of the effluent :-

-: It was observed that as the pH of wastewater was dropped to as low as 2.0 because of the settling properties of the effluent are increased tremendously. This could be due to the precipitation of negatively charged lignin components and the bacterial cells due to increased protonation of the medium. Colour intensity increased, as the pH was made alkaline up to 10.0. Thus, suggesting that pH plays a crucial role in the colour of pulp, paper mill wastewaters [50].

--Effect of an additional source of carbon :-

Extra carbon source assumes significant part in debasement process. Numerous studies demonstrated that the addition of nutrients like glucose and sucrose increased the ability to remove colour by approximately 20-25%. However, this could be attributed to the hydrogen ions that were present in the sample (pH), which decreased to less than 4.0 after 24 hours. Additionally, there is a negative impact on the sample's practical applicability due to the excessive growth of biomass, which results in high turbidity. Given the technology's practical applicability, the authors therefore rejected the use of additional carbon-rich nutrient sources [51].

--- LIMITATIONS OF BIOREMEDIATION AND WASTE MANAGEMENT :-

--Despite the fact that bioremediation is an ecological amicable
process, it has specific restricting elements too. In the case of in situ remediation, a number of additives are added to increase the microbes' capacities for degradation. Numerous other microbes in the same environment may be disrupted or harmed by these additives [52]. Even if genetically modified organisms are used, it becomes increasingly difficult to eradicate these organisms from that particular environment over time.

In order to achieve a predetermined level of remediation, bioremediation requires a lot of labour, is expensive, and takes a long time. Additionally, not all compounds are biodegradable or capable of complete and rapid degradation. The physical state of contaminants and waste, such as solid, liquid, gas, and so on, can have an impact on their nature [53].

--Bioremediation and degradation produce a number of compounds that are either more toxic or last longer than their parent compounds. Microbes can be killed or slowed down in growth by these toxins. Likewise, biodegradation requires explicit kinds of microorganisms for specific foreign substances or poisons; ideal ecological conditions for the corruption to happen; and optimal levels of nutrients or contaminants; etc. Enormous scope bioremediation tasks are challenging to do as contrasted with research center or pilot scale projects [54]. The general public's ignorance of the seriousness of the problem is the primary impediment to effective waste management. What's more, absence of satisfactory regulations, framework and institutional deficiencies restricted monetary and HR, lacking short also, long haul arranging, and so forth. aggravate the issue, resulting in waste accumulation [55].

- RECOMMENDED TREATMENT PROCESS OF PULP AND PAPER MILL EFFLUENTS :-

---Before being discharged into receiving water bodies, pulp and paper mill effluent treatment has become an essential prerequisite. There are generally two main types of remedial actions taken to reduce pollution from the pulp and paper industries :-

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1) Internal treatment at the source of the process, using "cleaner" technologies to reduce toxicity at each stage of papermaking;
2) End-of-pipe EOP treatment, which deals with discharged effluents [56].

-Biological oxygen demand :-

--- The various characteristics of pulp and paper mill effluent can be described, including its dark brown colour, temperature, highly alkaline pH, BOD (40,000–50,000 mg/l), and COD (200,000 mg/l). One tone of paper, it is estimated, produces 150 m3 of extremely lethal effluent [57]. As a result, in order to avoid the negative effects of pulp and paper mill effluents, a comprehensive management strategy is required. The existence of organisms capable of degrading various mill effluents is necessary for the industrial application of biotechnology. The BOD experiment was carried out under the optimized conditions of temperature (45 °C) and pH (6.5), employing the untreated sample as a control. As a result, we evaluated the capacity of B. cereus for BOD using treated and untreated effluent samples. After 36 hours of incubation, we observed rapid and effective degradation rates for the BOD, which resulted in a 66% reduction after 72 hours. The BOD level remained almost constant and did not decrease significantly after 72 hours of digestion [58]. The amount of dissolved oxygen that organisms use to break down organic complexes in waste is known as BOD, and it is frequently used to measure the quantity of pollutants in wastewater. Our findings demonstrate that B. cereus is capable of successfully reducing BOD in pulp and paper mill effluents [59].

--- The paper industry has been compelled to develop novel methods to reduce the various contaminants in effluents from the bleaching plants of the paper and pulp mills thanks to public opinion and government regulations on ecological pollution. Utilizing biological methods, for example, makes it possible to develop environmentally friendly and more sustainable processes that can reduce the amount of toxic compounds used in pulp and paper mill effluents. The majority of Pakistan's factories and mills lack appropriate treatment strategies, despite the country's rapid industrialization. The habitat that is adjacent to bleaching plants can suffer severe damage as a result of the presence of various pollutants in the effluents that are discharged from those plants. This study's B. cereus strain is able to withstand, decolorize, and reduce toxic and recalcitrant compounds found in high concentration in pulp and paper mill effluents, making it a safe method of disposal [60].

-Chemical oxygen demand :-

--- Industrial organizations' primary goals in their efforts to reduce energy consumption and safeguard the environment from contamination and toxic waste are to reduce the use of physical methods and hazardous chemicals for paper and pulp effluent treatment.

The use of biological techniques and the development of new technologies for the treatment of pulp and paper mill effluents are receiving a significant amount of attention. Microorganisms are primarily necessary for the removal of colour and the reduction of industrial effluent BOD and COD [61]. The COD parameter is used a lot to figure out how much organic pollution is in effluents. As a result, our findings that a significant drop in COD was observed in samples of discharge from contaminated pulp and paper mills and paper mills demonstrate that B. cereus is capable of effectively degrading these pollutants, further demonstrating that this microbe has the potential to bioremediate effluents from pulp and paper mills [62].

II. Conclusion :-

- Utilizing microbes, bioremediation offers an effective approach for dealing with various waste categories and types. Not only can waste materials be disposed of through bioremediation, but it can also be used to get rid of unwanted substances from the air, water, soil, and raw materials in paper wastes. In a world that is rapidly running out of resources, it is essential to recover recyclable and reusable materials. A significant amount of energy that could have been recovered from these materials could be lost as a result of improper waste management practices. Using bacteria to decolorize effluent from pulp and paper mills, bioremediation has produced outcomes comparable to some of the best decolorizing activities described in this literature. Further exploration is expected to foster quick biodegradation processes which are probably going to give a financially achievable interaction.

--Future outlook :-

- Genes for the efficient degradative enzyme could be cloned into bacteria and then transferred to suitable fungi. It could also be effective for future if we want to completion of bioremediation on a large scale for paper waste which is a major problem for world.

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