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Comprehensive study of using by product materials for treatment of wastewater: A review

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Abstract:

As industry expands, a significant quantity of industrial and domestic wastewater is released into water, resulting in water pollution and deterioration of water quality. Industrial wastewater contributes to water scarcity, endangers human existence and progress, and has become a global concern. As a result of the production of beneficial substances required for human life growth, massive amounts of industrial by products which generated as solid waste. Numerous industries globally are commonly produced of byproduct wastes such as fly ash, CKD, PKD, wastepaper sludge ash, in addition to slag wastes such as (iron, steel, nickel, copper, and metallurgical). Nowadays, recovering waste from industry has been observed in a sequential approach in decreasing environmental concerns in sustainable and economic approach by fixing an environmental problem and regulating disposal difficulties. The current study presents a comprehensive review on the industrial by product waste such as steel and iron slag, cement kiln dust, plaster kiln dust, wastepaper sludge ash and fly ash and its application in wastewater treatment.

Keywords: wastewater treatment, iron and steel slag, cement kiln dust (CKD), plaster kiln dust (PKD), fly ash, wastepaper sludge ash.

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Introduction

Wastewater from industries is defined as the sewage and wastewater discharged during the manufacturing process. With the expansion of industry, a huge amounts of domestic and industrial wastewater have been discharged into water, resulting in water contamination. Industrial wastewater exacerbates the scarcity of water resources, endangers human existence and development, and has become a global issue that everyone is worried about[1].

Rapid expansion in the manufacturing industry has provided comfort to people in recent years, but it also generates large volumes of effluent containing poisonous components such as nitrogen, phosphorus, hydrocarbons, and heavy metals, which have a severe influence on the environment and civilization [2]. There are numerous industries that rely substantially on water to carry out their different processes. Industrial wastewater is crucial to handle because of its potential to harm the environment and human health [3].

Industrial and cooling activities frequently generate wastewater including chemicals and solid particles [4]. Painting, tanning plant, and textile wastewaters include highly toxic and organic bio refractory chemicals that are harmful to human health. Before being disposed, these effluents demand effective and environmentally beneficial solutions [5]. Paper mills generate enormous amounts of effluent and sludge waste. This causes a number of issues with treatment of wastewater, contamination discharge, and disposal of sludge. Because wastewater can be toxic and dangerous, it should be treated before being discharged into the environment [6].

Huge amounts of industrial byproducts may be generated as solid wastes as a result of the manufacturing of useful substances needed to support human life development .Cement kiln dust, fly ash, (steel and Iron) slag, nickel slag, copper slags , waste paper sludge ash, metallurgical slags, plaster kiln dust , (zinc and lead) slag, salt slags, phosphorus slags , waste incineration slags, and other waste materials are often produced as products waste by many different industries located around the globe [7] .

Reusing of manufacturing waste products is currently occurring in a step-by-step modality in order to address environmental issues in cost-effective and friendly ways by solving an environmental problem and regulating disposing challenges. The removal of pollutants, the removal of coarse particles, and the removal of toxicants are all part of wastewater treatment. Furthermore, wastewater treatment eliminates pathogens while providing biomethane and new compost for agricultural use. Wastewater treatment is an important component of the effort to reduce wastewater, alleviate strain on natural water sources, and pave the path for clean energy. [8].The aim of this review is focusing on industrial by-products waste as inexpensive materials and possibility of using these wastes in wastewater treatment.

Wastewater Contaminants

Petroleum, fuel oil, and other hydrocarbons with concentrations range from (5 - 100) mg/L the most common types of pollutants found in power plant effluent. Calcium and magnesium carbonates, iron and aluminum hydroxide, organic compounds, hydrochloric and sulfuric acid salts are all examples of carbonates from chemical plant [9]. Because of their toxicity and prevalence in industrial wastewaters, phenolic chemicals have received increased attention among hazardous organic compounds. Organic compound in wastewater has been approximated as a quantity comparable to biological oxygen demand (BOD) or chemical oxygen demand (COD). Nevertheless, the use of tertiary treatment procedures for removing nutrients and organic debris is increasing [10]. Contamination with heavy metals of aquatic environments is a global environmental issue due to the negative impacts and accumulation through the food chain. Since industry and civilization have grown, the presence of heavy metals in wastewater have become more prevalent in industry sectors such as the plating, mining, batteries, rayon , pesticides, , tanning, fluidized bed bioreactors, metal rinse processes, petrochemicals, textile industry, paper , and metal smelting, heavy metal-contaminated wastewater penetrates the environment, threatening human health and the ecosystem[11]. Heavy metals generally not biodegradable and potentially carcinogenic; thus, their presence in high amounts in water may create major health concerns. Heavy metal ion removal from wastewater is crucial for maintaining environmental purity and human health. Various heavy metal ion removal techniques for different sources of wastewater have been investigated [12].

The most prevalent heavy metals detected in wastewater are lead , nickel , zinc , mercury , cadmium , copper , arsenic and chromium [13] . Heavy metals are metals that have an atomic density higher than (4 ±1) g/cm^3. These non-biodegradable metals are among the most harmful contaminants existing in industrial effluent, and they can significantly alter the physicochemical and freshwater biological quality [14].

Heavy metals pollute natural resources since they do not decompose in nature. Heavy metals in water, such as chromium, mercury, lead, arsenic and cadmium, are extremely harmful to the health of human even at trace quantities. Heavy metals disrupt with organ development and function at concentrations greater than a few g/L, poisoning the human body and destroying tissues and internal organs through a variety of mechanisms including enzyme denaturation, ion replacement, and protein inactivation [15].

Wastewater treatment methods

The fundamental aim of wastewater treatment technique is removing pollutants, large particles, toxic compounds, and potentially pathogenic microbes from the effluent so that it can be discharged back into the environment for a variety of purposes.[16,17]. Approximately more 770 million people worldwide are not capable of accessing safe drinking and household water [16]. Various methods of treatment minimize the quantity of contaminants in water as well as the content of suspended particles, the molecules of which can taint rivers and block water passage in pipes and channels after deposition figure (1). It also reduces the amount of biodegradable organic compound in the atmosphere, as measured by the biological oxygen demand (BOD).

Adsorption, membrane, ion exchange, filtration, electrodialysis, ultrafiltration, and reverse osmosis, are examples of physicochemical removal procedures [18]. Presently biological treatment techniques are regarded as a great option for industrial treatment of wastewater due to their low treatment costs, high efficacy. Recently, treatment of the industrial wastewater using a bioreactor has been proven to be one of the best approaches available. Reactors are the most important component of any bio-technology based process for enzymatic or microbial biodegradation, bioremediation or biotransformation [19] .

Separation units that function on differences in relative volatility are examples of possible physicochemical approaches. Volatile organic compounds (VOC) and absorbed optically bound halogens (AOX) are examples of potentially occurring volatile chemicals. The benefit of using these physicochemical approaches is the ability to recover and recycle the organic pollution components stated above [20].

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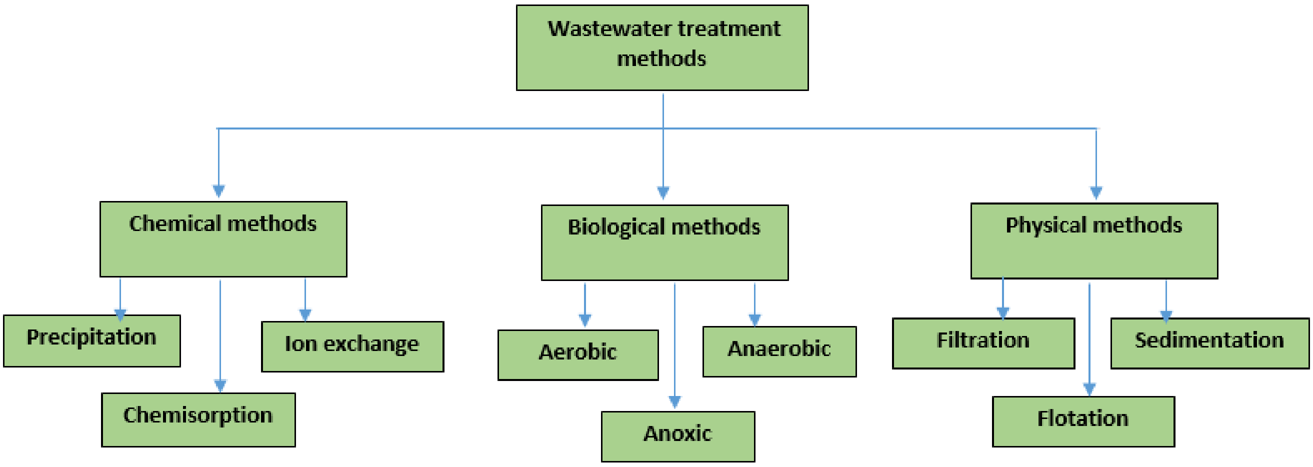

Figure (1): The schematic of wastewater treatment methods

Among most economical and environmentally friendly advanced oxidation technologies is wet air oxidation. It appears to be a promising method for treating organic contaminants in industrial wastewaters. Aqueous waste in wet air oxidation, undergoes oxidation in the liquid phase at pressures (0.5 to 20 MPa), extreme temperatures (125 to 320 C) and in the presence air. The technique has several advantages, including low operating costs and reduced air pollutant outputs [21]. Physical-electrocoagulation and chemical oxidation methods for removing organic compounds from industrial wastewater to assure a high degree of removal before release into sewage [22]. Sorption is one of the ways that have been successfully used treatment of industrial wastewater using industrial by-products wastes. Polymeric resins, and multiple inexpensive adsorbents (industrial by-products, steel and iron slag, PKD, CKD, silica, chitin, bentonite, and fly ash etc.) have all been employed as sorbents for of treatment of industrial effluents [23] .

By product waste

1. Steel and Iron slag

Slag is a byproduct of the iron and steel industries. For every ton of rolled iron or steel produced, half to one ton of slag is generated [24]. Iron slag has been categorized as a solid waste byproduct (figure 2) of iron and steel mill production operations. According to previous research, approximately fifty million tons of such a slag are generated worldwide each year. Such massive amounts of water can accumulate across large expanses of the land, leaving them not suitable for agricultural uses [25].

Figure (2): iron slag [52]

Steel and iron slags are produced throughout the crude steel and pig iron production processes. .The ferrous metallurgical industry's slags are divided into four categories: slag of the basic oxygen furnace steelmaking, blast furnace, slags of secondary metallurgical process, and finally the slag of electrical arc furnace. Because disposal of such slags necessitates a wide landfill area, they damage the atmosphere, subsurface water, and soil. Iron (for BF), calcium, magnesium, silica, and aluminum are the primary constituents in the slag, with trace amounts of heavy metals such as Cr, Ni, Pb, Zn, and others. These elements are mostly found in the form of oxides [26]. Furthermore, steel slags (which contain a substantial amount of chromium and a small amount of nickel) can emit as much as 1 ppm of Cr. As a result, increasing the utilization rate of slags and employing an alternate waste management options can be a major step toward achieving sustainable development in the ferrous metallurgical industry [27] . Table 1 shows the chemical composition of iron slag [28].

Table (1) Chemical composition of iron slag [28].

Particulars	Proportion
SiO_2	28.23%
Al_2O_3	3.25%
Fe_2O_3	62.45%
MnO	1.13%
MgO	1.83%
P_2O_5	1.45%
SO_3	0.89%

2. Cement kiln dust

Cement kiln dust (CKD) is a waste substance that is usually designated for landfills and is an industrial by-product created throughout the making process of cement. It is a fine powdery substance that resembles Portland cement figure (3) . Cement kiln dust (CKD), a fine, powdery, highly alkaline substance, is collected from cement kiln exhaust gas using cyclones, electrostatic precipitators, or bag filters. The characteristics of CKD vary according to the fuel type, kiln design and operation, kiln feed composition, and type of dust control systems used [29]. Because cement is manufactured in volumes ranging (2.5 - 4.0) billion tons per year, the CKD might be made in enormous quantities. In Iraq, there are several refineries, pipelines for transferring products of petroleum, firms of industrial, sanitary facilities, and facilities of agricultural; yet, these structures have the potential to be substantial polluters of groundwater resources. Furthermore, one ton of cement produces 41 kg of by-product CKD, implying that massive amounts of CKD will be discarded in the environment[29,30].

Figure (3): cement kiln dust (CKD) [59]

Wet and dry process kilns represent the two prominant kinds of cement kiln processes. Where, the first one accepts slurry feed materials, whilst the second accepts dry ground feed materials. A dust collection system routes the exhaust gases from the cement making process. A portion of the CKD gathered by the cyclone could be retrieved to the kiln. One ton of cement yields approximately (0.06 to 0.07) ton of cement kiln dust. Worldwide cement production is predicted to rise from 3.27 billion metric tons during 2010 to aboutn4.83 billion metric tons in 2030, with almost 220 million tons of cement dust emitted yearly from cement producing plants. The primary constituents of cement kiln dust, according to X-ray diffraction studies, are calcite ($CaCO_3$), quartz (SiO_2), and calcium sulfate ($CaSO_4$). Because of its limited leaching capabilities for heavy metals, CKD is generally non-hazardous table 2. However, its prolonged exposure to open air may have serious consequences for the environment. Cadmium, selenium, and lead, are all trace components present in CKD in amounts below 0.05% by weight. However, because such elements are effectively harmful and their concentrations vary amongst cement manufacturing plants, it becomes critical to evaluate their mobility in addition to their leach ability in the CKD [31].

Table (2) Chemical composition of CKD [31]

Chemical	CKD (wt%)
AL_2O_3	3.5
SiO_2	15.37
CaO	58.85
Fe_2O_3	3.08
K_2O	7.00
MgO	1.55
Na_2O	4.37
SO_3	5.66
Loss on ignition	23.79

3. Plaster kiln dust (PKD)

The gypsum sector generates a substantial quantity of plaster kiln dust by-product waste .The calcium sulfate dihydrate that should be calcined to generate is referred to as gypsum. Gypsum is a supply material for the plaster and can be used as a retarder in the industry of cement. Gypsum ($CaSO_4$. $2H_2O$) is a gray or white natural mineral occurrence of calcium sulfate dihydrate. Gypsum must be partially dehydrated to generate plaster, or calcined to produce calcium sulfate half hydrate ($CaSO_4$. $12H_2O$), also known as stucco. Most plants calcined to make stucco at temperatures ranging from (120-150 °C). One ton of gypsum calcined yields 0.85 ton of stucco, with the remainder representing particulate matter figure 4 (called plaster kiln dust, PKD) discharged as a byproduct from the gypsum factories. Every year, millions of tons of gypsum are generated globally, and the amount of dust emitted into the environment may be predicted [32]. Plaster kiln dust is a solid and white powdered material that is recovered and collected from massive gas emissions through smoke chimneys or smokestacks positioned at the end of the plaster kiln (or gypsum kiln) production facility. Fabric filters and electrostatic precipitators are frequently used to regulate emissions in plaster (gypsum) kiln operations.

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Figure (4): Plaster kiln dust [52]

4. Wastepaper sludge ash

Wastepaper sludge ash, a low-cost and abundantly available raw material, is of particular interest as an effective material of construction. Wastepaper sludge ash (WSA) represents a byproduct of the incineration of the paper sludge produced by paper mills, the recycling paper sector, and wood biomass waste, figure (5). Every year, amounts of paper sludge of thousands tons are created all over the world, resulting in WSA ash in amounts of thousands tons. The industry of pulp and paper in Europe yields about eleven million tons of WSA each year, 70% of which is obtained from the deinked recycled paper production [33].

Figure (5) :Wastepaper sludge ash [54]

The main components of WPSA are lime, and silica. Except for MgO (4%), the quantities of the other key elements were minimal (less than 2%). As a result, it comprises of Al_2O_3, Fe_2O_3, MgO, SO_3, K_2O, in addition to other compounds. Dewatering at low temperatures (200°C) and incineration at high temperatures (>800°C) can both reduce volume/weight. Organic chemicals are usually burned at temperatures ranging from 350 to 500°C during incineration, whereas inorganic salts and mineral fillers are converted into the equivalent oxides at extreme temperatures (exceeding 800°C). Among the most abundant oxides in paper sludge ash are CaO, Al_2O_3, MgO, and SiO_2 [34].

Despite the fact that the effective recycling routes for sludge ash (WSA) from wastepaper are investigated like amendments of soil, stabilization of soil, road sub layers, cement partial replacement in the concrete industry, and the production of the lightweight aggregates and plaster blends of blocks, ashes of large volumes remain difficult to treat or recover.[35] . Paper sludge is often utilized as sorbent materials following particular treatment, including the absorption of

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contaminants such as ammonium (NH^{4+}) present in industrial, agricultural and domestic wastewaters [36]. Many researchers have evaluated the paper sludge and WSA as non-hazardous to the environment [37].

The increasing rate of population is increasing the pace of production of paper waste, which is also increasing since paper is replacing plastic products such as paper bags and cardboards around the world. Apart from that, the consumption of cement is increasing day by day, reducing the natural resources available for its manufacture [38].

5. Fly ash

Fly ash is a type of residue produced during the combustion. The mineral impurities within coal (quartz, clay, shale, and feldspar) fuse during burning figure (6). Fly ash is a byproduct of thermal power plants (TPPs) having an annual production of around 112 million tons. The cement and concrete industries account for 50% of overall fly ash consumption, which currently stands at 30MT (28%). Other applications include low-lying area fill (17%), roads and embankments (15%), a dam building (4%), brick production (2%), and new sites for the safe disposal of fly ash, which is a source of air pollution. [39].

Figure (6): fly ash [60]

Fly ash can range in color from brown to dark gray basing on its mineral and chemical composition. Tan and pale colors are usually accompanied with high lime concentrations. Iron concentration is commonly associated with a brownish color. A high unburned percentage is usually responsible for the appearance of dark gray to black. The color of fly ash usually seems quite consistent between power plants and the coal sources. The particles of fly ash have spherical shapes and are ranging in size from 0.5m to 100m. They are mainly composed of the silicon dioxide (SiO_2), which is in turn available in two common forms: the amorphous form (smooth and rounded) and the crystalline form (pointed, sharp, and deadly); the aluminum oxide (Al_2O_3), and the iron oxide (Fe_2O_3). Fly ashes are frequently quite heterogeneous, with a mixture of glassy particles and crystalline phases like mullite, quartz, and different iron oxides.[31].

Previous studies

Several studies and investigations have been undertaken for the usage of industrial byproduct waste as inexpensive materials in the wastewater treatment sector. Such industrial wastes possibly to be recycled to create new adsorbents for treatment of contaminated water, exemplifying the green and sustainable synthesis strategy that reduces the negative human health and environmental implications of industrial by-products and processes.

In water and wastewater treatment plants, filter beds or reactors using smelting slags can be employed to remove specific pollutants. Iron and steel slag are applied as engineering materials in the filter beds, reactive barriers for treatment of contaminants in groundwater and industrial wastewater such as Pb, Cr(VI), Cd, DCE , and TCE. Blast iron furnace slag is regarded as a low-cost sorbent for removing Co^{2+} and Pb^{2+} ions from aqueous environments [40]. Toxic metals and chlorinated solvents can be treated using reactive slags as barrier media [41,42].

Iron and steel slags, have been used as low cost adsorbents for extracting anions and cations from the industrial wastewater. Without a doubt, the physical, chemical, and phase chemistry features of slag based sorbents influence their performance. For example, the existence of the crystalline phases offers a considerable effect on the capacity of adsorption. Despite their reduced cost and widespread availability, the chemical and the geometric heterogeneity of slag-based adsorbents has a considerable impact on their performance and applications[43]. Steel slag has a fairly strong filtration ability for removing phosphorus from water [44]. Iron slag can be considered as a byproduct produced in large amounts from recycled residues of iron and steel plants; thus, the idea of employing this waste to remove Benzaldehyde from polluted water provides an interesting issue in the realm of sustainability. The removal efficiency was 85% for the interaction of slag and Benzaldehyde contaminated water [45].

Many studies had been investigating the application of CKD for treatment of contaminated water. A low-cost composite made of CKD and sewage sludge waste that applied as permeable reactive barrier for treatment of aqueous solution polluted with tetracycline [46]. Research results indicated that CKD was successful for removing water pollutants and heavy metals. In comparison with the performance of the alum as a coagulant, it exhibited very high closed efficiency. Its elimination percentage ranged from 61.2 to 97.2% [47]. Cement kiln dust (CKD) was examined as an affordable, abundant adsorbent for the removal of Cr^{+3} from the simulated wastewater. The data revealed that significant adsorption occurs for Cr^{+3} at pH values less than 4. The CKD performance towered Cr^{+3} ion adsorption from aqueous solution was investigated using a series of isothermal batch experiments. The optimal conditions for the adsorption of Cr^{+3} on CKD were 60 minutes, 200 rpm, 20 g/L CKD, and pH value 4 [48].

CKD has also been used successfully as a treatment agent in a variety of sectors, including the removal of zinc and copper pollution from the acidic groundwater. Here, CKD contributes to efforts to eliminate the threat of cadmium-contaminated groundwater. The use of waste material of CKD as a treatment agent could give numerous benefits in this industry [49]. The results demonstrate the viability of employing cement kiln dust as a good coagulant for municipal wastewater at an optimum dosage of 2 g/L [50]. Cement Kiln Dust (CKD) was used as an adsorbent to remove copper with efficacy of 99% from simulated wastewater [51].

A unique composite sorbent produced from industrially process includes alum, a low-cost component, as well as the plaster kiln dust as a byproduct waste from the gypsum industry and CTAB as inexpensive and abundant components, designed for the removal of heavy metals in groundwater using a permeable reactive barrier (PRB) approach [52]. Use composite magnetic plaster kiln dust (MPKD) as a revolutionary low-cost adsorbent for reuse of by-product PKD pollution.

Cadmium (II) ion removal effectiveness was investigated as a function of pH (4-7), MPKD mass (0.5- 8 g/L), initial ion concentration (50- 350 mg/L), and shaking period (5- 180 min) [53]. An innovative sustainable reactive sorbent (CFO-SS)) formed from wastepaper sludge ash and iron ions was developed and demonstrated to successfully removal tetracycline from contaminated water [54]. The use of fly ash as an adsorbent has a positive effect in removing various pollutants from wastewater such as COD, BOD and TDS [55]. Because of its high porosity and adsorption capacity, coal fly ash bed is a low-cost and effective method for removing COD, TSS, TDS, and reducing pH. Fly ash, which is abundant in coal-fired power stations, can be effectively used for wastewater treatment [56]. According to the findings, involving fly ash into the planned slow sand filtration system dramatically reduced turbidity, color, suspended particles, and chloride while also significantly increasing DO concentration. As a result, it may be appropriate for low-cost small-scale home grey water treatment for non-potable uses such as irrigation[57] . The features of coal fly ash, such as shape, surface area, porosity, and chemical composition, make it an attractive material for prospective use in wastewater treatment [58].

Conclusion

Using industrial byproduct wastes in wastewater treatment is the greatest technique for solving both waste management and water quality issues. In the ferrous metal industry, increasing the slag's use rate and implementing another option of waste management can be a significant step toward attaining sustainable development. Previous research has shown that CKD, PKD, and wastepaper sludge ash are cost effective and efficient methods of eliminating water contaminants. The structure, surface area, porosity, and chemical composition of fly ash make it an appealing material for potential application in wastewater treatment.

Author Contributions Statement

All authors: collection and analysis of data, research write were done by the author.

Declaration of competing interest

The authors declare that there were no competing interests.

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