Valorisation of water hyacinth for different engineering applications

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Valorisation of water hyacinth for different engineering applications

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Abstract. Nature has many elements that can be beneficial or harmful. One of these elements is water hyacinth (WH) which is an aquatic weed found in water bodies such as rivers and lakes and it has an invasive nature due to its rapid growth rate. On the contrary, water hyacinth, despite its classification as an invasive plant species, possesses a multitude of industrial and engineering applications, demonstrating substantial potential for valorisation into various products. Its versatile attributes and widespread availability render water hyacinth a viable resource for deployment across several sectors, including wastewater treatment, bioenergy generation, bioremediation, and sustainable agriculture. The objective of this paper is to analyse methodologies for the valorisation of water hyacinth, with the explicit goal of mitigating its adverse environmental effects.

Keywords: Water hyacinth, Valorisation, Hydro char and Anaerobic digestion

1. Introduction

1.1 Chemical composition and historical background of water hyacinth

Water hyacinth or Eichhornia crassipes can be defined as an aquatic freshwater plant or weed whose origin was in the Amazon River and as time passes it spreads out in the whole world knowing that it has a very high growth rate making it spread very fast. Water hyacinth contents are approximately 20% cellulose, 48% hemicellulose and 3.5% lignin which makes it available for many valorization methods. It is unique for its round-shaped leaves and spongy-like stems along with a lavender-colored flower and its high tolerance and adaptivity made it easy to spread everywhere [1]. In Egypt, water hyacinth started to spread in the 19th century when it was first brought for aesthetics for its flower then it started to spread widely such that it contributed to negative consequences later due to its rapid which made it form dense mats on the water surface [2].

1.2 Environmental concerns of spreading of water hyacinth

Water hyacinth is considered notorious, it has a very negative impact on the environment, where it contributes to habitat disruption, blocks the sunlight, and prevents the reach of oxygen to the water

underneath. The formation of the extensive mats on the surface causes aquatic life to fall apart and thus reduces the biodiversity in water bodies. Water hyacinth also absorbs nutrients from water such as phosphorus and nitrogen. The depletion of these nutrients alters the nutrition balance of water bodies and lowers the food availability for fish that rely on those nutrients [3]. When water hyacinth decays in water, the chemical characterization of the water underneath changes [4]. As a result, the pH and oxygen levels change dramatically and affect the marine life. In some areas, the spreading of water hyacinth can block the water flow causing a lack of water in some regions and floods in others, so it needs to be regularly removed. It can also cause clogs in waterway impacting transportation and trading paths through water which has a high negative impact economically. The accumulation or dissemination of water hyacinth can foster environments conducive to disease vectors, thereby heightening the risk of transmitting serious illnesses [5].

1.3 Water hyacinth management challenges for valorization

Owing to the distinctive composition of water hyacinth, coupled with its extensive spread and environmental impact, researchers have directed their attention towards the conversion of water hyacinth into high-value products suitable for various industrial and engineering applications. However, water hyacinth management and valorisation encounter many challenges due to many factors. The main obstacle is its invasive behaviour and rapid growth rates which create a huge challenge in managing and handling it [6]. Water hyacinth mats can be harvested and collected mechanically to reduce the clogging of waterways. It can be also chemically controlled in which substances like herbicides might be used. However, this could ruin the water quality of rivers and lakes and make the situation worse. Therefore, seeking smarter management goals and introducing different strategies will achieve balanced control and valorised products besides preserving the ecosystem and the aquatic life [7].

1.4 Different technologies for processing and synthesis of valuable products from water hyacinth

Some technologies are commonly used to process and valorise water hyacinth. Technologies can be divided into chemical, physical and biological conversion methods. For chemical conversion, procedures like pyrolysis, hydrolysis and hydrothermal carbonization can be used to convert WH into a valuable product [8]. Physically, water hyacinth can be converted to products using technologies like mechanical pressing to extract fibres. Biologically, it can be treated by fermentation, anaerobic digestion and composting [9].

1.5 Water hyacinth as a source of biogas production

The production of bioenergy from water hyacinth is a broad path with many procedures and many outcomes. The most known procedure is anaerobic digestion which is defined as a biological process in which microorganisms break the organic matter down in special conditions as the absence of oxygen resulting in the production of a biogas rich in methane as a byproduct of the process where this gas can be utilized in generating electricity and can be a source of cleaner fuel. A study was performed in which water hyacinth was collected, chopped, and mixed with water then put into a digester for a certain incubation time where after 4 days the biogas started to be produced and when the produced biogas was analysed. Its composition was 58% methane and 45% carbon dioxide gas so it can be used in cooking or lighting houses. The ratio of water hyacinth to water in the digester was 1:1 and the drum of the digester was polyvinyl chloride then gas was collected in form of balloons to be analysed by gas chromatography [10].

1.6 Water hyacinth as a source of bio-oil and bio-char production

Another bioenergy production method from water hyacinth is pyrolysis which is a process that includes heating water also in the absence of oxygen to produce biochar, bio-oil, and syngas to be applied in soil enhancement while syngas and bio-oil are sources of green energy. Biochar is well known for being used in the storage of carbons in soil to enhance its quality where a study was done in which samples of water hyacinth were subjected to air to be carbonized in limited quantity at a temperature range from 200^{o}C to 500^{o}C in time range of 30 to 120 minutes. It was noticed that the yield of biochar decreased by temperature and time, but the stability of carbon increased. The optimum conditions recorded were 300 to 350^{o}C and 30 to 40 minutes. The product showed potential in increasing carbon stability and aromaticity in soil. Soil respiration was enhanced by 1.9 times [11]. In addition, a study was done using water hyacinth from Egypt to perform lipid extraction then transesterification at certain conditions using hexane, chloroform, ethanol, ether, acetone, and methanol. The percentage of lipids was 6.79-10.45 % and by transesterification it

produced biodiesel with concentrations of 3.22-6.36 %, the yield is small due to the small amount of lipids in water hyacinth [12].

1.7 Production of hydro char from water hyacinth

There is also hydrothermal carbonization of water hyacinth to produce hydro char which has several applications from being used as soil fuel to usage in construction and enhancing construction material. In this process, water hyacinth is added with deionized water at high temperature and pressure inside an autoclave to yield hydro char. Studies on this procedure used a time range of 30 minutes to 24 hours in a temperature of 240^{o}C where results showed no difference after 4 hours and the heating value in the produced hydro char varied from 16 to 20 MJ/Kg such that for every 6 grams of oven dried and sieved water hyacinth, 100 grams of deionized water were used and build up pressure was used on the predetermined temperature then apparatus was washed and the product was filtered then dried where the solid phase is the hydro char and the aqueous phase can be centrifuged to make sure all suspended solids are removed where this hydro char can be used as in other fields rather than energy production as adsorption and water treatment [13].

1.8 Water hyacinth as an adsorbent in wastewater treatment for heavy metals

Water hyacinth is applied widely in the removal of heavy metals and dyes from water where it showed a capability to accumulate metals from wastewater as zinc and lead as it acts as a natural filter that reduces toxicants from water. Research was performed where a healthy water hyacinth plant showed efficiency in the removal of cadmium, arsenic, lead and copper with concentrations varying from 0.2 to 5 mg/L in five pots with 100 g WH in each pot and after 30 days the removal percentage varied from 59-92% which shows good efficiency of removal [14].

1.9 Water hyacinth as an adsorbent in wastewater treatment for dye removal

For dye removal, the process includes drying water hyacinth leaves, stems and roots in an oven for a day then blending to a diameter of 0.01 mm, Congo red dye was tested for adsorption with a concentration of 70 mg/L in a buffered solution with pH 6 where the reaction was carried at a temperature of 28^{o}C using 0.15-6 g of dried WH along with 50-250 ml of the dye solution then and time range of 15-60 minutes then after filtration results showed that the dried WH can be reused for 6 times with removal percentage of 56% which shows a capability to be used in treating textiles wastewater [15].

1.10 Water hyacinth in materials engineering as a bio-composite

One of the unique properties of water hyacinth is that it can contribute highly to materials engineering as it can introduce innovation and sustainability. Fibre extraction from the plant contributes to the manufacture of textiles which helps to create green and guilt-free products. The method used is alkali treatment which achieved fibre crystallinity of 80% as mentioned before [16]. Hyacinth can also contribute to producing bio-composite materials which are reinforced with the extracted fibres and can have applications in the construction, automotive and furniture industries [17].

1.11 Water hyacinth in production of supercapacitors

Water hyacinth also contributes to the production and enhancement of supercapacitors as a green energy storage device. A study was done on a bilayer separator that is eco-friendly and on paper supercapacitors using manganese oxide (MnO) and carbon black (CB) where the bilayer separator plays an important role in preventing the contact between negative and positive electrodes thus preventing short circuits and improving efficiency where this separator was made from nanofibers extracted from water hyacinth where it had a porosity of 46%, electrolyte uptake 94% and lower wettability than that of Celgard Tri- layer separator and had a lower bulk resistance which causes higher conductivity with 136% that the latter separator, it also showed higher efficiency and specific charge capacitance which is a huge benefit of creating environmentally friendly energy storage devices [18].

2. Valorisation of water hyacinth

2.1 Social benefits of water hyacinth valorization

Socially, the valorisation of water helped in creating job opportunities in Nigeria where a program for recovery and management of water hyacinth was established and it created more than 5000 job

opportunities either directly or non-directly in weaving, biofuel production or even handicrafts and same occurred in Bangladesh where 2500 jobs were offered by implementing water hyacinth management techniques along with reduction of diseases that arise from the spread of this plant such as reducing mosquitos which reduce malaria and dengue diseases [19].

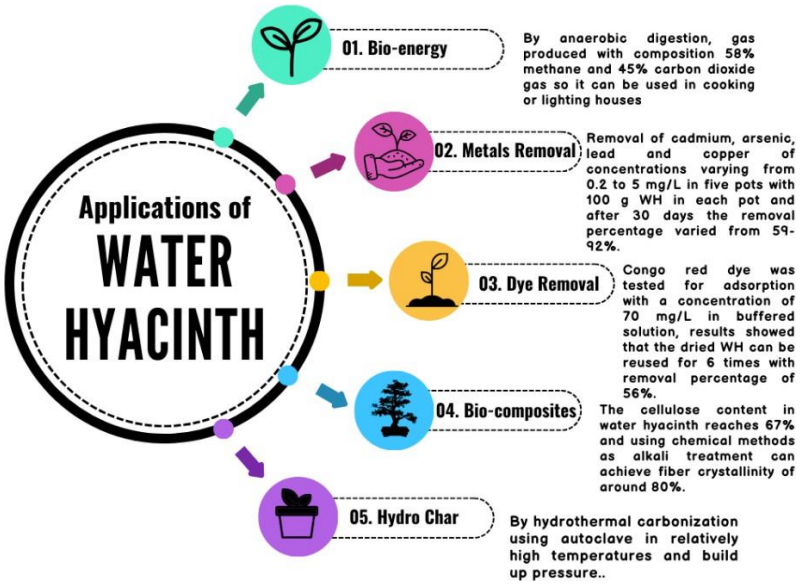

Figure 1: Engineering applications of water hyacinth

2.2 Environmental benefits of water hyacinth valorization

Valorisation of water hyacinth is very beneficial environmentally as it turns a toxic plant to ecosystem into a source of many valuable products instead of being a biowaste that increases contaminants on the earth's surface as it contributes to waste reduction by reducing the spread and abundance of water hyacinth in different water bodies thus reduce clogging of waterways and opposition of the photosynthesis process. The valorisation process also helps to improve water quality in some regions by Phytoremediation, but it must be controlled to prevent the previously mentioned consequences and it also can improve soil quality in some regions [20]. When harvested, can produce bioenergy in different forms which if applied widely can reduce the usage of non-renewable energy sources and thus reduce air pollution and offer more sustainable and green solutions.

2.3 Economic benefits of water hyacinth valorization

Economic benefits are diverse due to different applications of water hyacinth such that the biogas production could generate an annual revenue ranging from $20,000 to $50,000 which can differ according to daily prices and energy demand. Also, a ton of water hyacinth can sell biofertilizers with a range from $5,000 to $20,000 depending on market prices. Handicrafts from water hyacinths make an annual revenue varying from $10,000 to $100,000 which shows that implanting valorisation techniques of water hyacinth in industries can create a very high economic enhancement [21].

2.4 Challenges and future directions of water hyacinth for different engineering applications

Many future directions can be followed to benefit from water hyacinth spreading. In the adsorbent path for dye removal, water hyacinth can be tested for the removal of other dyes like azo dye to see its potential to be used for wastewater treatment in industrial plants. It can also be implemented in the production of hydrochar on a large scale to be able to benefit from its applications. The production of bioenergy from WH can be elevated using different conditions to see the difference in yield. The diversity of applications available to valorise WH makes it a source of income for regions it is widely spread.

3. Conclusion

In conclusion, water hyacinth can be considered as a threat to the environment due to its invasive behaviour, blocking waterways, sunlight and even absorbing important nutrients from water which irritates the balance of the aquatic ecosystem. The plant showed numerous valorisation techniques. Water hyacinth can be valorised in many fields starting from water treatment, bioenergy production, fibres and materials for engineering purposes and it can even produce energy storage devices and enhance the already existing ones. For wastewater treatment, water hyacinth proved efficient in the adsorption of heavy metals with a removal percentage reaching above 90% and removal of Congo red dye reaching 56%. Also, experimental work was performed to produce green and renewable energy sources such as bioethanol and biogas using methods like anaerobic digestion which lowers biomass waste and reduces the risk of air pollution from non-renewable energy sources. In materials engineering, water hyacinth was used to extract fibres where the crystallinity of fibre reached 80% which gives it the potential to produce furniture and other products. Regardless of the multiple ways of valorisation, it's still challenging to apply these methods on a large scale due to challenges in the cost of harvesting and synthesis along with the controlling and monitoring of any of those applications so it is under study to explore and find efficient methods to valorise this aquatic plant as it will be a huge economic and environmental benefit for the regions it is widely spread in.

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