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Value-Added Products of Rice Husk in Various Disciplines

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Abstract: Oryza sativa is a highly produced crop for human consumption and survival so as the most ever waste-generating crop in Asian parts of the world, this creates problems due to its ancient disposal system that occupies large spaces and harms the environment in many ways. Thus, in order to present this waste as a golden opportunity for economic development and sustainable development, this review aims to mention different value-added products like bioadsorbent, biofertilizers, bioinsulators, and superhydrophobic coatings that would show a great utilization of agricultural waste. One of the most studied products is bioadsorbant showing a very high absorbing capacity towards methylene blue and As (V) in the groups of dyes and metals respectively. Biofertilizers are found to be a good and better alternative to chemical fertilizers by having higher shelf life and a good carrier of microbes. Due to very high silica content, Rice Husk was found to be a better bioinsulators on the basis of lower thermal conductivity properties. This presence of silica which gives sufficient roughness also made it possible to produce superhydrophobic coatings better than other coatings. All four products have been thoroughly reviewed, which still require further research for other value value-added products. This review can give a most important direction towards **lignocellulosic biomass utilization in different applications rather than just using it in the production of biofuel.**
Keywords: Rice Husk Value-Added Products, Bioadsorbent, Biofertilizers, Bioinsulators, and Superhydrophobic coatings.

I. INTRODUCTION

Oryza sativa is one of the most grown crops in different regions [1] which covers approximately 1% of the earth's surface [2]. These are specially cultivated in Asian countries[3]. Due to the presence of various nutrients (such as carbohydrates, amino acids such as lysine as a first limiting amino acid, and beta-carotene as vitamin A precursor), it supplements people with calories and is very much favorable in growing children [4], [3].

A. Global Trade of Rice

According to FAO, in 2021, the production of rice worldwide has increased by 2.2 million tons from the year 2019 to 2020. Utilization in 2020/21 reached a record level of 514 million tons driven mainly by food use and a mild recovery in non-food uses of rice, for animal feed in particular. World trade of rice in 2021 (January-December) remains largely unvaried at 48 million tons. In the year 2020, India produced a record high of 182.2 million tons of paddy, whereas China, the output of paddy was estimated at 211.9 million tons, indicating being the world's largest rice producer of rice/paddy whereas India is the second [5], [6]. 90% of the total global rice is produced from Asian regions. Rice plays a very important role in the world economy [7] but exports from China and India are relatively low due to their huge population needs [8].

B. Processing of Rice

Rice is a monocotyledon plant with the genus Oryza having two further two species, namely Sativa and glaberrima, natively found in Asia and Africa, respectively [8], [9]. Rice belongs to the grass family (Poaceae) [10]. There are 21 wild species too [9]. *O. sativa* has high quality and yield and is commercially grown in 112 countries.

Grains of rice have different components as layers [3]. Rice kernels are mainly composed of Rice Husk, rice bran, and starchy endosperm having a portion of approximately 20%, 11%, and 69% respectively [12] which is produced by ideal milling. Rice milling is called as a process of removal or separation of husk and bran to obtain the edible portion for consumption [12]. Husk and brown rice together makes the paddy rice produced just after the threshing process. After husk removal, brown rice is produced consisting of bran layer, germ, and the endosperm part (white rice). Brown rice is milled further to remove the bran layer and germ to produce white rice [12], [13]. Fully milled rice contains whole and broken grains [12]. Thus, rice grains need to undergo different milling steps. A common rice milling system is a multi-stage process [16]. This machine separates all the side products like straw, dust, sand, stones, etc., from paddy [17].

Rice Milling has three general stages:

1) The cleaning [18]and husk removal stage is also called shelling [13] by *Paddy Husker or Paddy Sheller* [17].
2) The scouring [18] / bran removal (whitening) and polishing stage by *Rice Polisher* [17] and
3) The grading- broken and head rice is separated [13], blending, and packaging stage [12] for dust-free bagging [13].

This milling process is needed to be handled with care to prevent breakage of the kernel and improve the recovery of rice. Rice quality and its value are determined mainly by milling process quality to meet the consumer's preference for polished grain over rough grain [19]. The milling process also plays role in improving rice nutrition, cook time, and sensory characteristics [20].

C. *By-Products of Rice Milling*

The major product of rice milling is rice (endosperm) with a yield of 70 %, and the rest 30% is the unconsumed portion of paddy produced as a by-product which includes Rice Husk, rice bran, and rice germ [3]. The rice by-products are divided into two categories i.e., starch-rich and lignocellulosic substrate. Starch-rich category includes rice bran, broken, unripe and discolored rice whereas the lignocellulosic substrate includes Rice Husk [21]. Traditionally, these byproducts were considered waste which led to indiscriminate burning of the waste resulting in environmental pollution [22].

If these byproducts could have alternative utilization, then could promote improved yield and sustainable rice production as an economic booster for rice-producing nations [23], [20]. In recent years, rice by-products have attracted very high attention as functional foods due to their high amounts of vitamins, minerals, and fiber, which can help to lower cholesterol and enact anti-atherogenic activity [24]. Rice by-products are richer in nutrients when compared to polished rice [3]. Rice bran has been seen to provide nutrition and received high attention whereas other rice byproducts have applications in agriculture. Importantly, Rice Husk is mainly considered as burning waste to recover energy. In other fields like animal feed, Rice Husk has limited value due to its low digestibility and bulk density. They are also used in cosmetics, construction materials, and as food additives [20].

1) *Rice Husk:* Rice Husk is a major by-product obtained by the rice milling process [25]. These are the protective coverings of rice grains [26] protecting them from physical damage and attacks by pathogens, insects, and pests in the paddy plant before milling [27]. Annually, around 12 million tons and 80 million tons of Rice Husks are produced in India [28] and worldwide respectively [29]. Rice Husks have an irregular boat-like shape [30] with a hard surface [31]. It is very lightweight, having a packing density of 122 kg/m3 [30] with high silicon content, and thus difficult to get decomposed by bacteria [5]. The main elemental components of Rice Husk are C- 37.05 wt.%, H- 8.80 wt.%, N- 11.06 wt.%, Si- 9.01 wt.% and O- 35.03 wt.% [31]. Rice Husk biomass is comprised of three polymers, i.e., cellulose (35%) hemicelluloses 15% and lignin (16%), and ash (20%) together with a small amount of starch (up to 7%) [32], [21]. It is considered as cheapest biomass in all lignocellulosic biomasses. Organic substances like cellulose and lignin make up 75-90 % of Rice Husk, while mineral components like silica, alkalis, and trace elements make up the balance [32]. It is a crop by-product having uniform size and high ash content of about (14–25%) [33].

D. Management of Rice By-Products

Rice milling waste is not hazardous waste, but its management is very important due to its larger volume of waste [39]. Only a little portion of Rice Husk produced is utilized consciously out of that large proportion of agro-industrial waste worldwide [40]. Rice Husk has a high level of fiber and low protein and energy which makes it a little difficult to convert it to a value-added product. More reasons hinder its use like lack of awareness, less understanding of technology, economic problem, etc. [41]. So, there is a need for the identification of major opportunities for using and increasing the value of the waste [41] and reducing the cost of waste treatment [32] with both qualitative and quantitative points of view [40].

Sustainable development is crucial these days. The "triple bottom line" approach can help achieve sustainability. This makes sure that environmental, economic, and social aspects are considered altogether with equal importance. This helps to identify the consequences of activities' impacts on all environmental, economic, and social aspects, in turn, taking actions to build a sustainable society [42].

Agricultural wastes are generally the byproducts that are not seen from a utilization point of view and even are of the very huge sector. To solve this problem, these byproducts are being subjected to many pieces of research to make them useful which created many value-added products from the generated waste which is mentioned in this review.

II. BIOADSORBENT

Due to industrialization, wastes are generated in water bodies in huge amounts which affects aquatic life, agricultural products and so human health [43]. The main sources that generate waste are:

1) Elemental waste is generated from industries based on metal plating, mining, tanneries, painting, car radiator manufacturing [44], printing and photographic, smelting, batteries, paper, painting, petroleum refining [43] as well as agricultural industries where fertilizer and fungicidal spray, pesticides are excessively used to protect agricultural products [44]. Elements like Cu, Zn, Cr, Cd, Ni, Co, Pb, Hg, As, etc. are harmfully non-biodegradable wastes thus get accumulated and contaminate groundwater and other natural wastes streams [44], [43] where it is usually discharged [45].
2) The dyes as a major waste products are discharged into water bodies from industries based on textiles, rubber, paper, plastics, cosmetics, etc., to color their products which are hazardous and may pollute the environment, aquatic life, and different food chains [44].
3) Other than these wastes, there are some generalized organic pollutants disposals causing water toxicity like phenolic and polycyclic hydrocarbons, pesticides and herbicides, fertilizers, biphenyls, detergents, greases, oils, and pharmaceutical compounds. These are mutagens and carcinogens which accumulate in the environment affecting health [49], [50].

A. Strategies Toward Clean Water Bodies

As these pollutants need to be ceased before they stream into water bodies are gaining a lot of concerns these days. There are a few strategies (layer filtration, coagulation, adsorption, oxidation, particle trade, precipitation, ion exchange, carbon adsorption [51] biodegradation, oxidation, ion exchange, precipitation, adsorption, coagulation, flocculation, filtration, irradiation, electrodialysis, reverse osmosis, membrane process, ozonation, distillation and solvent extraction [43] accessible for the expulsion of all the pollutants from wastewaters. However, only some of them were used on account of their minimal expense, high effectiveness, appropriateness to a wide variety of toxins, and low maintenance costs [46]. Thus highly economical alternate technologies or sorbents for the treatment of metal-contaminated waste streams were needed.

Sorption could be an extremely effective procedure because of low money investment, easy handling and operation, rapidity, and accessibility of various adsorbents without the formation of toxic substances. [52], [53], [54]. An adsorbent ought to have many characteristics like accessibility, non-toxicity, affordable, high surface capability, high abrasion resistance, and environmentally stable [49], [55]. The adsorption process is affected by many experimental parameters such as contact time, initial concentration, pH, particle size, agitation rate, competitive ions (2055 R), the effect of temperature [46], agitation time, sorbent dosage [45], flow rate and characteristics of the column in continuous operation [43], the effect of modifications/treatments [57].

B. Other Wastes as Bioadsorbants

A kind of suitable adsorbent is Rice Husk which is readily available at low cost and has been proved to be a good sorbent over others. However, there are many more biomaterials that are being used for the adsorption technique to remove unwanted dyes and metals from water resources such as cashew nutshell [56], apple pomace [58], banana peel, orange peel, peanut hull [59], Indian rosewood [60], wheat shells [61], hazelnut shells, cherry tree [62], eucalyptus bark, Rubberdddd sawdust, black gram husk, Waste tea leaves, Papaya wood, Powder of green coconut shell, jack fruits, Neem leaf powder [63]wheat straw [64], soy meal hull [65], grapefruit peel [66], banana stalk [67], sugarcane bagasse [68], coconut shell [69]which have good efficiency to adsorb different adsorbates. To date to make the adsorbents highly effective, by increasing the surface area of the adsorbent in the pretreatment step there are many modifying agents have been used such as NaOH, HNO_3 [59], Formaldehyde, sulphuric acid [60], Citric acid [64], H_3PO_4, $ZnCl_2$ [70], potassium hydroxide (KOH) and carbon dioxide [67], HCl [68].

For Rice Husk Epichlorohydrin, Tartaric acid, 4M N-(3-chloro-2- hydroxypropyl) trimethylammonium chloride, Orthophosphoric acid, and Polyaniline are the modifying agents [71].

C. Rice Husk as Bioadsobents

Rice Husk is used as a sorbent in removing heavy metals and dyes and has been intensively studied and reported. There are much value-added modifications done to Rice Husk to make it work as sorbent. These modifications produced many kinds of adsorbents as a product such as:

Zeolites [72], biochar [73], silica gels, pretreated powder, activated carbon, Silica Activated Carbon Composite, Rice Husk ash, etc. Adsorption properties of Rice Husk have been studied because of its low price and richness in silica [74].

There are many metals on which studies are carried out like: As(V), Cd, Co, Cr (III), Cr(VI), Cu, Hg, Ni, Pb and Zn [44], Cu, Pb(II), Zn(II), Ni(II) [43], selenium [75]. [76] showed that the amount of Pb ions adsorbed per unit mass of Rice Husk is more than the other ions with this trend: Pb > Hg > Cd > Cu > Co > Mn > Zn > Ni. [77] Showed Pb adsorption was higher than Hg (10.86 and 3.23 mg/g, respectively). [114] showed that metallic ion adsorption by activated carbon with maximum adsorption in the order Cd(II) > Cu(II) > Zn(II) > Hg(II).

The maximum adsorption capacity for each metal ion from previous works has been summarized in table:1. The values of referenced adsorption capacity should be considered as values under explicit conditions but not as maximal adsorption limits [44]. Table:1 shows that the adsorption of metal Pb is more effective than for other metals by Rice Husk modified adsorbents.

Table-I

The adsorption capacity for metal ion

S.no.	Adsorbate	Capacity (mg/g)	Reference
1.	As(V)	615.11	[78]
2.	Co (II)	0.32	[79]
3.	Cr (III)	1.90	[79]
4.	Cr (VI)	164.31	[78]
5.	Hg	66.66	[80]
6.	Zn	30.80	[81]
7.	Cu	31.85	[82]
8.	Pb	120.48	[83]
9.	Zn(II)	35.3	[84]
10.	Ni(II)	26.6	[85]
11.	Ar(V)	90.7%	[86]
12.	Cu(II)	112.43	[87]
13.	Pb(II)	207.50	[88]
14.	Cd(II)	164.31	[89]
15.	As(III)	1.22	[90]
16.	Se(IV)	40.92	[75]

Table:2 shows some of the dyes that have been effectively removed by the Rice Husk or modified Rice Husk made bioadsobant. It is clearly showing that Rice Husk has the highest capacity for adsorbing two dyes that are safranine and methylene blue.

[91] Shown order of effectiveness of adsorption process by various treatments Glutradehyde < methanol < ethanol < NaOH < NH_4OH < boiling < native < Triton X- 100 < heat treated < CTAB < MgSO4 < $CaCl_2$.H2O < NaCl < HNO_3 < H_2SO_4 < HCl. Boiling of Rice Husk showed zero effect on the biosorption capacity of the biomass. [92] Shown enhancement of sorption capacity after modification of biomass with HCl, H2SO4, and HNO3 acids.

Table-II

Adsorption Capacity for Dyes

S.no.	Adsorbate	Capacity (mg/g)	Reference
1.	Acid yellow 36	86.9	[93]
2.	Methylene Blue	1450-1950	[94]
3.	Indigo carmine	4.86 (95%)	[95]
4.	Crystal Voilet	44.87	[96]
5.	Acid yellow 17	12.98 (97.97%)	[97]
6.	Basic Green 4	511	[98]
7.	Basic Red 2	838	[99]
8	Basic Blue 9	312	[99]
9.	Safranine	838.00	[99]
10	Direct Orange-26	19.96	[100]

There are many other organic compounds that have been studied for their adsorption capacity by Rice Husk such as: ammonium [73], phenol [101], humic acid [102], pyridine [103], alpha picoline [104], Dibenzothiophenes in kerosens [105], Naphthalene, Phenanthrene [106], 2,4-dichlorophenoxyacetic acid [107], Catechol, Resorcinol [108], NH_4Cl, slurry solution [109].
[110] depicted the adsorption in dairy wastewater using Rice Husk. In this example, the phenomena of adsorption were favored by a lower temperature and pH. Maximum removal as high as 92.5% could be achieved using an adsorbent dosage of 5 gm/L, pH of 2, and temperature of 30ºC. In [111] Rice Husk is also being used as ash to produce Thiol modified magMCM-41 nanoparticles for the adsorption of herbicides 2,4-D and glyphosate showing adsorption efficiency between 60-70% with different optimized factors like pH, temperature, contact time, etc. In [72] Rice Husk and waste aluminum cans were used as silicon and aluminum sources, respectively for the synthesis of some nanosized zeolite, zeolite/zeolite, and geopolymer /zeolite products for the removal of Co(II), Cu(II), and Zn(II) ions from aqueous media and show its cost-effectiveness. Rice Husk powder was found to be better than acid-treated Rice Husk powder in [112], [113], where it was employed as a cheap efficient bioadsorbent for defluoridation of water. In [115] Rice Husk was coated with aluminum to make it a better adsorbent for the removal of fluoride from drinking water. According to the research, the method can remove up to 10 mg/g of fluoride. The other end products from Rice Husk that can be used to develop bioadsorbents are depicted in Fig. 1

III. BIOFERTILIZERS

Agriculture is a prominent practice that rules the economy in developing countries [116]. Presently, soil and agriculture management strategies are mainly dependent on continuous high usage of agrochemicals such as chemical fertilizers, pesticides, and water, with the increasing use of extracting machines to gain maximum output in less time is a great achievement for agricultural industries [117], [118]. However, excessive use of chemical fertilizers, composts, and pesticides is not only of high cost but also a thing of environmental threat [118]. Chemical fertilizers cause air and groundwater pollution by an increase in the concentration of P, N, and other excess plant nutrients in water bodies that deteriorate the water quality and the depletion of dissolved oxygen [119]. Chemical fertilizers also deteriorate soil ecology, degrade soil fertility and show harmful effects on human health [120].
Therefore, naturally occurring biofertilizers and composts could be a good alternative to chemical fertilizer which enhances nutrient rotation and the biodegradation process using microorganisms [121]. Biofertilizers are accepted as inputs for organic agriculture by the International Federation of Organic Agriculture Movements (IFOAM, 2005). The quality of the carrier is a vital factor in determining the microbial load and shelf life of biofertilizers [122]. Currently, Rice Husk is used as a bulking agent for composting [123] and carrier materials for biofertilizers [122]. Different carriers have been used such as Rice Husk ash, vermiculite, peat, wheat bran, alginate, and clay which are regarded as good materials for use as a carrier [124].

A. Microbes for Biofertilizers

Biofertilizers contain living organisms that colonize the rhizosphere of the plant and act as stimuli for plant growth by increasing the availability of primary nutrients [125]. Plant Growth Promoting Rhizobacteria (PGPR) is the group of many soil bacterial species on which many commercial biofertilizers are based [117], [121]. On the basis of bacterial species, there are 4 types of biofertilizers like Nitrogen fixing biofertilizers, Phosphorous solubilizing biofertilizers (PSB), Phosphate mobilizing biofertilizers, and Plant growth-promoting biofertilizers. Microorganisms like: *Rhizobium, Azospirillum, Azotobacter (N_2 fixing bacteria), Bacillus, Pseudomonas,* and *Aspergillus (*P-solubilizer*), Mycorrhiza (phosphate mobilizers), Pseudomonas* sp. (Plant growth promoter) [117].
According to reports, Organic farming increases soil composition, fertility, and soil fauna, all of which benefit crop productivity in the long run [116]. [123] observed that composter Rice Husk resulted in significant increases in Ca, Mg, Si, K, and Na concentrations of the in situ soil solution compared to the control treatment and the concentrations of Al, Mn, Fe, and Zn (as toxic elements for crop growth if present in excess amounts) significantly decreased.
[131] depicted the change in the growth of Soursop (Annona muricata L.) in the presence of Rice Husk Biochar (RHB) and compared it with growth in the presence of arbuscular mycorrhizal fungi (AMF). It was observed RHB, either individually or in combination with AMF, had significantly improved the growth performance of soursop seedlings at the nursery stage indicated by a significant increase in shoot and root biomass, root length, root surface, area, and leaf area meter. [132] determined the potential of some biochar as a carrier of biological fertilizer for swamplands. It was estimated the better quality of carrier material of different microbes. Biochar Rice Husks, are very effective as Trichoderma, Bacillus, and Azotobacter. Thus, Rice Husk biochar can be used as a carrier material as a single biofertilizer, as well as a consortium biofertilizer consisting of decomposer fungi, P solubilizing bacteria, and N-fixing bacteria.

[122] experimented over moisture content, bulk density, porosity and water absorption capacity, and pH of Rice Husk and cassava peel. Both carrier materials also supported the growth of the test organism which suggested the presence of nutrients and absence of toxicity. The molds in cassava peel became infected after 2 weeks while biofertilizer produced with Rice Husk, even after drying, remained viable for more than six weeks due to high silica (SiO_2) content, of about 19 % in Rice Husk which makes it less susceptible to microbial attack and therefore easier to preserve. Thus, Rice Husk has a higher shelf life to be used as biofertilizers. In [136] shown Rice Husk charcoal can operate as an adsorbent of organic chemicals such as fertilizers and insecticides, as demonstrated by its 38 mg g^{-1} Methylene blue adsorption capability. This allows for a slow-release effect on fertilizers for crop absorption, as well as a reduction in pesticide pollution.

Rice Husk ash was suggested as a superior carrier for supporting microorganisms in the bio-fertilizer process while also improving soil structure [121]. The treatment comprising Rice Husk ash as a carrier, combined with rhizobacteria in saline soil had the highest overall enzyme activity as measured by the fluorescein diacetate hydrolysis (FDA) technique. Rice Husk ash is a good source of carbon and silica, and the porous structure is helpful for microbes and moisture retention. This means that the plant can absorb silicon in a soluble form through its roots [137]. When opposed to using cell suspension directly into the soil, bacteria survive longer when immobilized in the carrier. Microorganisms can proliferate and survive for lengthy periods of time in these carriers [124]. Rice Husk ash also helps to improve soil structure by enhancing soil porosity, aeration, and moisture retention. As a result, using Rice Husk ash as a carrier proved successful in raising the soil microbe population and, as a result, plant development.

IV. BIOINSULATORS

Insulation is defined as the act of preventing heat, electricity, or sound from flowing or passing through a material, medium, or system [138]. Buildings consume most of the energy used for air conditioning in all seasons [139], especially in summer and winter, unless the roof and walls are well insulated. In buildings or any other thermal application, thermal insulation is a very important way to conserve energy. For buildings, insulation can reduce the rate of heat transfer between the air-conditioned area and its surrounding environment that is, reducing heat transfer between two zones having different temperatures [140] to maintain a certain temperature in any environment. In such circumstances, thermal conductivity is employed exclusively, so evaluating the thermal conductivity of the selected materials can aid in determining whether or not they can be used for thermal insulation purposes [138].

A. Characteristics of Insulators

Some of the basic properties which are generally considered for designing insulators are thermal property, absorption, hardness, and combustion, [141] i.e. low thermal conductivity, moisture protection, resistance to mold growth and insects [142] and non-flammability, non-toxicity, and higher strength [143], lightweight and good recycling characteristics, less costly. [140] as well as considered to be environment and human health friendly since today's popular inorganic insulation materials have a negative impact from the production stage to the end of their useful life. [141], [144]. Dielectric property and reliability are also the most important characteristics of any insulator [145].

B. Harmful Effects of Insulators on Environmental

Thermal insulating materials such as fiberglass, rock wool, mineral wool, polystyrene, polyurethane foam, and cellulose are extensively utilized, however they are detrimental to the environment [140]. The majority of thermal insulation baths include formaldehyde resins which can trigger asthma attacks [147]. Small particles from fiberglass and glass wool insulation can be harmful to one's health and respiratory system or skin irritation. [148] The use of hazardous, fire-retarding compounds like boric acid in cellulose insulation has been identified as having the potential to have significant health consequences [149]. Vice versa if we consider, that renewable fiber thermal insulation derived from trees, plants, or animals has the potential to regenerate itself, uses less energy to manufacture, and degrades quickly when discarded, resulting in a low environmental effect [150]. Thus, the majority of recent studies have concentrated on agricultural waste products, while others have looked into industrial waste materials, and only a few have looked into animal waste materials [140].

Coconut and sugarcane fiber, cotton, wheat straw, palm leaves, and oil palm fiber [151], coconut husk, maize cob or stalk oil palm shell, and leaves or straw from cereal crops with high fiber content [142], sugarcane bagasse [152], miscanthus fiber, sunflower stalk fiber [153], stubble fibers [154], food crop by-products [155], rice straw [156] [157], Rice Husk [158], wood fibers/textile fibers [159], coffee chaff [160], and corn stalk [161]. All of these materials can be used as the major component of composite materials, making them appropriate for the production of boards and panels [142].

Silica has an extremely low thermal conductivity of about 0.01–0.03 W/m·K. Biological silica comes from natural ash. Insulation using bio-silica has been carried out in the production of cordierite and forsterite and for extruded and pressed insulation [162].
Recent research has begun on insulators for construction utilizing RHA as a silica source [163]. Rice Husk products are poor in nutrients, have high wear strength, and contain a lot of ash. Ash has a very high quantity of silica ranging from 80% to 95%. The burning of Rice Husk produces different types of ashes based on the different process parameters used during husk burning. These ashes have different functions based on varied chemical, mineralogical and morphological characteristics [164] in husks burned below 70ºC, amorphous silica predominates, whereas crystalline silica predominates in husks burned above 70ºC [165]. Silica in ashes makes them have low thermal conductivity and mechanical characteristics, resistant to chemical etching (acid slag) and thermal shock (temperature changes above 60ºC). Because of the greater residual carbon content, coarse grains, presence of oxides, and poor crystallinity which helps to achieve low thermal conductivity, amorphous silica is useful in ceramic thermal insulators. As a result of these qualities, they could be employed as raw materials in industrial ceramic processes like thermal insulation [166].

C. Properties of Rice Husk Ash for Insulators

The following are some of the benefits of using RH ash: I it is obtained in very fine powder form, which saves energy for size reduction; (ii) it is relatively more reactive due to its amorphous nature and large surface area, which is expected to reduce the formation as well as sintering temperature of forsterite ceramics; and (iii) it is an agricultural waste, which reduces the cost of production [167].

There are certain materials that are used as additives to produce a usable and commercial insulator such as:

1) Plasticizers are added to provide viscosity and elasticity to the ceramic paste making the particles cohesive and aiding their flow during forming insulators as ashes lack the property of plasticity. Eg. Polysaccharide PS1, and polyvinyl alcohol (PVA). During the sintering process these additives are removed thus, don't hinder the final product chemically.
2) Pores-causing substances are used to increase the final porosity. The amount of substance is experimentally determined, in such a way that during forming and sintering laminating effect can be avoided. Eg. Wood sawdust.
3) Flux is added to support pore formation by absorbing water and swelling itself. On humidification, it becomes plastic which aided increased workability and formation of the ceramic paste. Eg. Bentonite. Its presence in the ceramic paste is beneficial [166].

[145] has examined for the dielectric value of a pressboard, that's used inside the transformer, and was covered with 3 components: epoxy resin, Rice Husk ash, and quartz powder. Quartz powder and Rice Husk ash were combined in a specific ratio with the epoxy resin. The dielectric constant of the covered pressboard is 3.273 at 1 kV and volume resistivity is likewise excessive at 3.18 ×1013Ω•cm at 500V DC supply for the covered pressboard which was better than the non-coated press board (2.650 at 1 kV). [169] used a biodegradable poly (butylene adipate-co-terephthalate)/poly (lactic acid) (PBAT/PLA) blend binder and four different types of locally available by-products (Rice Husk, wheat husk, wood fibers, and textile waste fibers), composites were made by hot pressing. The Rice Husk composite with a density of 378 kg/m3 had the lowest thermal conductivity, 0.08 W/mK. After 24 hours of immersion in water, the Rice Husk composites had a minimum water absorption of 42%. By replacing traditional building materials with the created biocomposites, the environmental effect will be reduced.
[163] organized and integrated ash (RHA) and RHA-derived silica aerogel as a filler (0-10%) into low-density polyethylene (LDPE) resulting in a composite where the overall performance of each filler had been compared. Thermal stability of both the composites with fillers was being upgraded as compared to unfilled LDPE however among the silica aerogel and RHA filler's composites, silica aerogel had a better performance than RHA as filler in the composites. Silica aerogel as filler indicated thermal insulation strength with 0.0926-0.1820 W/m.K as compared to RHA at 0.3275-0.3532 W/m.K and unfilled LDPE samples at 0.3889 W/m.K. Both fillers showed better thermal stability however the addition of silica aerogel as a filler (2-10%) indicated higher thermal stability and thermal conductivity than RHA.
[171] determined the thermal conductivity for a mixture of Rice Husk fiber and gypsum and 100% gypsum. Four samples have been tested with different ratios of gypsum and Rice Husk. The evaluation resulted in a decrement in thermal conductivity with the increment of Rice Husk fiber in the sample. The value of thermal conductivity of the sample having less ratio of Rice Husk is 0.772W/mK whereas the sample with a high ratio of Rice Husk had 0.7368W/mK. Rice Husk shows thermal properties of insulator when mixed with gypsum and thus could be used as plaster ingredient and ceiling finishing.

In [138] the mixture of Rice Husk and Plaster of Paris was evaluated as insulation materials. The addition of 1% Rice Husk has proven a minor impact on the insulation properties of Plaster of Paris, 3% of Rice Husk gave higher insulating properties and proven to be the best combination of insulating properties, strength, and porosity.

Whereas 5% concentration of Rice Husk increased the porosity of the structure and allowed more heat to flow thus the thermal conductivity recorded was higher.

The effects revealed that the addition of Rice Husk to the mixture to just a concentration would display better thermal insulation and after exceeding quantity might increase porosity in turn increasing thermal conductivity. In [142] the potential for using Rice Husk, Bagasse, and Corncob composite samples as thermal insulation materials have been investigated.

According to the findings of the assessments, sample G with $0.231 Wm^{-1}k^{-1}$ of thermal conductivity and $22.114 m^{-1}$ of specific heat was the best combination with 60% of Rice Husk and a significant proportion of bagasse to a smaller percentage of the corncob. The overall assessment shows the commendable insulation property of Rice Husk as well as increased insulation property of insulators when mixed with Rice Husk.

V. HYDROPHOBIC COATINGS

Superhydrophobic surfaces (water repellent/ weatherproof surfaces) [173] are in great demand in recent years as per their requirement in different industries such as automobiles and medical industries, etc. [174]. Most importantly these can be used in the field of construction as penetration of water into concrete does more than just cause destruction by expanding, but also allows the invasion of corrosive chloride ions. Therefore, hydrophilic concrete production needs to be stopped to prevent deterioration and structural damage to concrete. Different types of water-resistant materials can be used to reduce the wetting of concrete [175].

A. Properties of Superhydrophobic Surface

Various research works have been carried out to create a superhydrophobic surface. The idea of adding additional properties of different sectors such as anti-corrosion, anti-icing, anti-fogging, self-cleaning, and anti-fouling, to the superhydrophobic coatings which have unique structure [174] to combat the adverse weather conditions [175].

Hydrophobicity of a surface is based on the principle of the angle between the water droplet and the surface. The greater the angle between them greater will be the hydrophobicity. Superhydrophilic, hydrophilic, hydrophobic, and superhydrophobic water contact angles (WCA) vary from 0° to 10°, 10° to 90°, 90° to 150°, and 150° to 180°, respectively. In superhydrophobic coatings, water droplets easily roll down from their surface [174].

Superhydrophobic coatings can either be generated by grafting hydrophobic groups including CH_3, CH_2CH_2, and CF_3 [176] or hydrophobic chemicals can be used including silane, siloxanes, and silicones [177] on the substrate to reduce the surface energy of concrete [176]. These silicon-based chemicals contain hydrophobic alkyl groups to prevent wetting [175]. To modify the substrate surface ultra-violet technique, photo-polymerization and spray technique [174] lithography techniques, phase inversion, surface etching, sol-gel method [178, 179] self-assembly [180], templating [181], chemical etching [182], electrospinning [183] and chemical vapor deposition [184] which have been reported.

Besides these, nanoparticles (such as nano-silica, titanium dioxide, zinc oxide, etc) [174] can be added to the substrate to generate the required roughness [176] affecting its morphology at the nanoscale dimension 35 for the production of superhydrophobic coating. It is time-saving and affordable and even there is no requirement for expensive equipment or rigorous conditions. [175]. As a result, the most common superhydrophobic coating formulation is made up of a hydrophobic polymer and inorganic nanoparticles distributed in a solvent. Various types of hydrophobic polymers were studied in the development of superhydrophobic coatings [187].

Matrix material for fabricating superhydrophobic coatings should have features like flexibility, good processability and low costs. These polymers generally have different structural and functional groups with suitable branches that are interconnected using the covalent bond to produce different configurations to use it where low adhesion and low friction are needed.

These materials can fulfill the need in the fields where self-cleaning, self-healing, anti-icing, anti-adhesion, and oil/water separation applications are required. The factors including nanoscale roughness, surface energy, coating thickness, mechanical stability, and bonding strength between the substrate and coating are responsible for attaining a superhydrophobic surface. [185, 186] Roughness in the micro and nanometer scale and a coating of low surface energy are the two essential requirements that needed to be met in order to create a superhydrophobic surface [188].

B. Rice Husk for Superhydrophobic Coatings

Due to silica as a Rice Husk constituent, it can suitably replace costly commercial nanoparticles. The ash should consist of amorphous silica instead of crystalline silica when used as a superhydrophobic coating [189] as it is used to create the roughness required by the superhydrophobic coating on concrete.

The high strength and comparatively low cost of nano-silica powders make them suitable for their use. If these silica powders can be extracted from waste products, then it would minimize the further costs. It would also help in controlling waste disposal and other related problems. Rice Husk is one such waste product available in abundance in Asian countries. Disposal of paddy and the left ash from burning is a major issue in many developing countries. [190]

Many types of research have been done in order to produce the best hydrophobic coatings made from biowastes. Junaidi et al. created a superhydrophobic covering made of Rice Husk ash and silica with photoluminescence characteristics (RHA). The RHA was calcined at 550 and 650 degrees Celsius to produce silica particles with a negligible quantity of carbon residual in this study. To make superhydrophobic coatings, the RHA-SiO_2 was chemically treated using 1H,1H,2H, and 2H perfluorodecyltriethoxysilane (HFDS). The water contact angle of the covered concrete was 157.7° [191].

Rice Husk ash was mixed in an ethanolic solution containing fluoroalkyl silane, 1H, 1H, 2H, and 2H-perfluorodecyl triethoxy silane to make the superhydrophobic coating (2 vol. percent). The ash solution was sprayed on top of a commercial adhesive coating that had been applied to the concrete. On the covered concrete, a water contact angle of 152.3 0.5 was measured. The total amount of water taken in was lowered by 40.38 percent, and the water sorptivity was reduced by 44.44 percent. Water penetration into the covered concrete was successfully decreased after 72 hours at 500 kPa water pressure, but not completely avoided [192].

Husni et al., sprayed the ash solution on top of a commercial adhesive primer layer that had been applied to the concrete. Water penetration into the covered concrete was reduced after 72 hours of testing under a water pressure of 500 kPa, but not totally avoided [195]. Overall, it is suggested that silica particles in Rice Husk ash may be employed to generate superhydrophobic concrete coatings. Rice Husk ash was disseminated in ethanol containing 1H,1H,2H, and 2H-perfluorodecyltriethoxysilane to make these coatings.

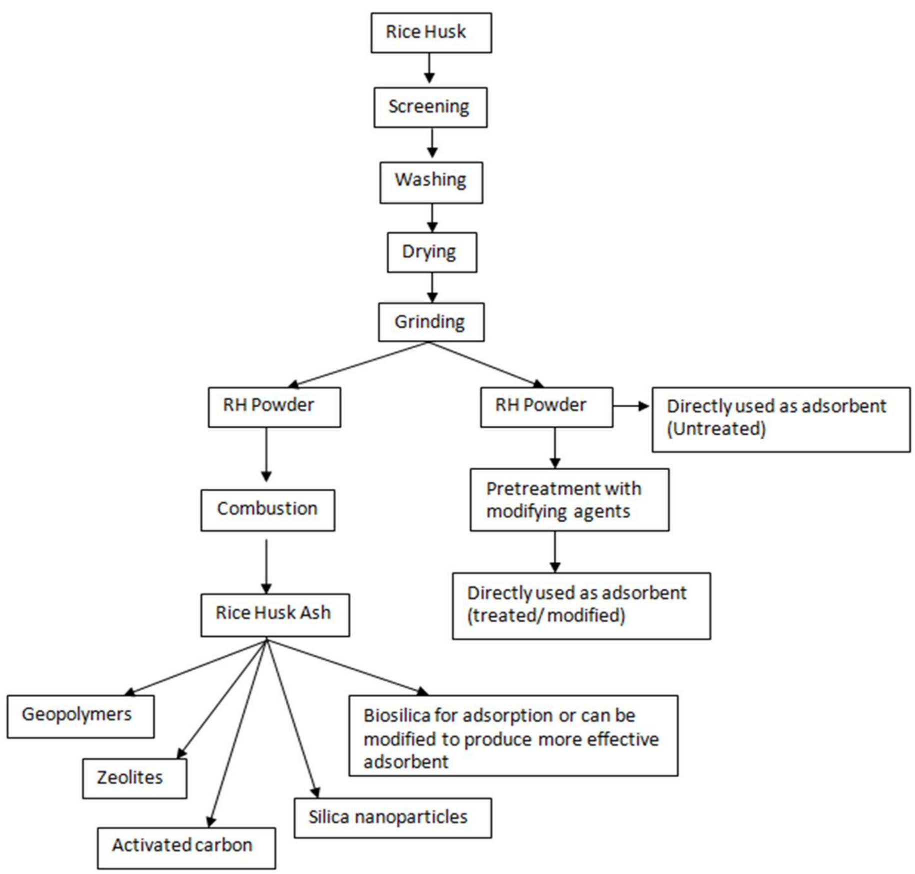

Fig. 1. End products made from Rice Husk which is used as effective adsorbents.

VI. CONCLUSIONS

The use of Rice Husk which is easily available and of low cost could solve the problem of its disposal while also lowering the cost of waste management. Rice Husk and ash are directly used in the production and synthesis of new materials.

One of the most researched products is a bio adsorbent made from Rice Husk that has a great capacity for adsorbing heavy metals and dye in various water bodies. By treating it with various chemicals, the adsorbing capability can be improved. Until now, Rice Husk bioadsorbent has been most effective in adsorbing methylene blue and As (V). Second, biofertilizers are an excellent alternative to chemical fertilizers since they enhance important elements in the soil while lowering hazardous elements. As a strong supplier of silica and carbon, it provides a good carrier for microbes and plants to flourish, extending their shelf life.

Then there are bioinsulators manufactured from Rice Husk, which have been considered because of their unique features and lowest thermal conductivity among all the other materials used to make bioinsulators, owing to a large amount of silica (80-95 %) in them. The use of Rice Husk reduces the overall thermal conductivity of composites when combined with other materials.

Finally, because of the increased silica content, Rice Husk is employed to create adequate roughness in order to make a superhydrophobic covering. This coating is primarily created by spraying a Rice Husk solution onto adhesive coatings, resulting in a higher quality finish. All four products were thoroughly examined, and it was determined that Rice Husk may be a better choice in many applications than other waste products, and that various improvements could be made to improve it. The various benefits of Rice Husk and Rice Husk ash can be realized through future vital research efforts, giving new energy for local and regional sustainable development.

Apart from enriching the properties of the products and launching value-added products, the Rice Husk is used to produce new products like biofuels, and bioenergy after subjecting it to microbial fermentation which is a major field of future research and studies in Science and Engineering.

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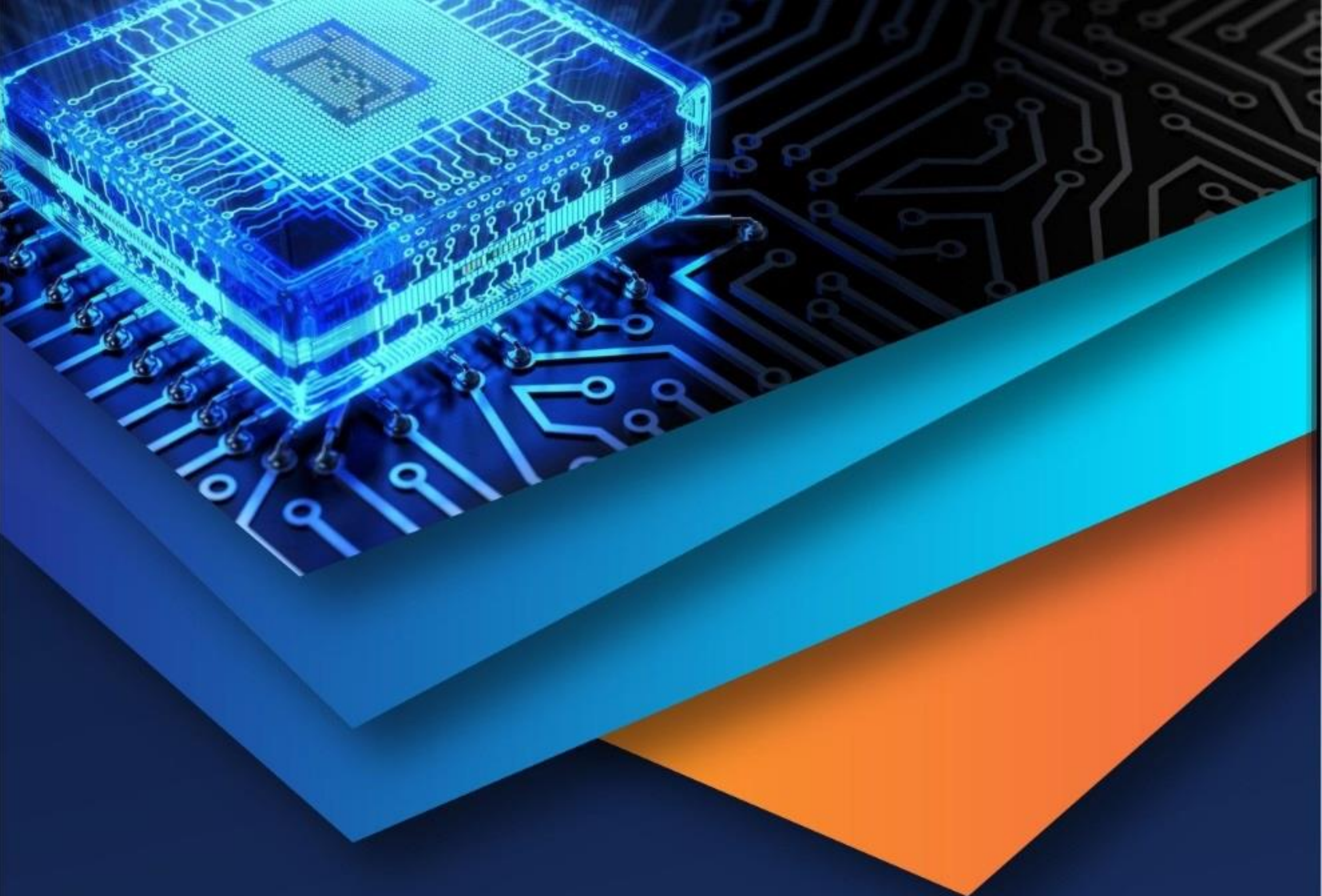

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