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Color Manufacturing by the Conversion of Microbial Stored Carbon using the Phase Change Principle

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Abstract:
Major reasons for air pollution are carbon emission from industries, which is responsible for 70% of the total air pollution. Carbon storage and capture are in great demand for the mitigation of the emissions. The method which is trending is carbon storage in microbes such as algae cells and fungi. There is a lot of research in reusing the stored carbon to manufacture into many products. One of them is manufacturing color dyes using various formulation techniques which are complex and skilled chemical engineers are needed. This paper gives detailed information on microbial fermentation, anaerobic digestion, and color manufacturing using the phase change principles. Phase change principles are used in most of the technologies like refrigeration and food processing industries. The manufacturing of color is discussed in the current article along with their intensity control based on the concentration levels, coarse size for various purposes.

Keywords: *Green house gases, microbial fermentation, carbon dioxide, anaerobic digestion*

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I. Introduction:

Color is manufactured in several ways, each with its unique process and materials. Here is a brief explanation of each method:

Dyeing: This process involves adding color to a substance such as fabric or fibers. Dyes are applied to the material either in a liquid or powder form and then heated or exposed to light to set the color. Different types of dyes are used depending on the type of material being colored, such as natural or synthetic dyes[1].

Pigment production: Pigments are solid particles that are mixed with a binder to produce paint or ink. The binder can be either water-based or oil-based and the pigments can be made from a variety of materials such as natural minerals, synthetic organic compounds, or metals. The pigments can be ground into a fine powder and then mixed with the binder to produce a final product[2].

Printing: This process involves transferring color from an ink or paint to a surface using a press or a printer. There are several printing methods such as screen printing, flexographic printing, and digital printing. The type of printing method used depends on the type of material being printed, the desired print quality, and the number of prints being produced[3].

Color filters: Color filters can be made by coating a surface with a material that absorbs certain wavelengths of light, producing a specific color. Color filters are used in a variety of applications such as color correction in photography and television production, and in medical [4].

Most of the black color is manufacturing from the carbon also called as Carbon Black. Carbon black is a fine, black, amorphous form of carbon that is widely used as a pigment, reinforcing filler, and conductive agent in various products, including tires, plastics, rubber, inks, and coatings. It is produced by the incomplete combustion of heavy petroleum products, such as tar, pitch, or coal tar. Carbon black has a number of unique properties, including high surface area, chemical stability, and electrical conductivity, that make it a useful material in a wide range of applications.

Carbon black is used as a reinforcing filler in various polymers, including polyethylene, polypropylene, polyvinyl chloride, and polystyrene, to improve their mechanical properties, such as tensile strength, modulus, and abrasion resistance. For example, the addition of carbon black to rubber can improve its strength and durability, making it useful for tires and other rubber products that are subjected to high stress and abrasion. In the plastics industry, carbon black is used as a pigment to darken the color of the final product and improve its light fastness and weatherability.

Other than the usage as a filler and pigment, carbon black also has applications in electronics and energy storage. The high surface area and conductivity of carbon black make it an excellent material to produce supercapacitors and batteries. Carbon black is used as the active material in the electrodes of these devices, where it provides high energy storage capacity and power delivery. The ability of carbon black to store electrical charge has also made it a useful material in the development of photovoltaic cells and other renewable energy technologies.

Despite its many useful properties, carbon black has also been the subject of concerns regarding its environmental and health impacts. Carbon black is classified as a human carcinogen by the International Agency for Research on Cancer (IARC), and its inhalation has been linked to respiratory and cardiovascular disease, lung cancer, and other health problems. In addition, the production and use of carbon black can result in the release of fine particulate matter and other air pollutants that can have adverse impacts on air quality and human health[5].

Carbon black is a versatile and widely used material that has several unique properties, including high surface area, chemical stability, and electrical conductivity, that make it useful in a wide range of applications. While the benefits of carbon black are clear, it is important to consider its potential health and environmental impacts and work to minimize these through the development of more sustainable production and use methods.

Carbon Black Manufacturing:

Carbon black is a material that is widely used in various industries for its unique properties, including its color. Carbon black is a fine, black powder that is produced from incomplete combustion of hydrocarbons, such as oil and natural gas. This process results in the formation of carbon particles, which are then aggregated and processed to create carbon black.

The production of carbon black starts with the pyrolysis of hydrocarbons in a reactor, which operates at high temperatures ranging from 700 to 1,200 degrees Celsius. The heat causes the hydrocarbons to decompose, releasing carbon-rich gases. These gases then come into contact with a cool surface, such as a cooled reactor wall, and the carbon condenses to form soot.

This soot is then collected and processed to create carbon black. The processing steps vary depending on the desired properties of the final product, but generally involve milling and classifying the soot to produce a fine powder. The powder can then be further processed to modify its properties, such as its particle size, surface area, and surface chemistry.

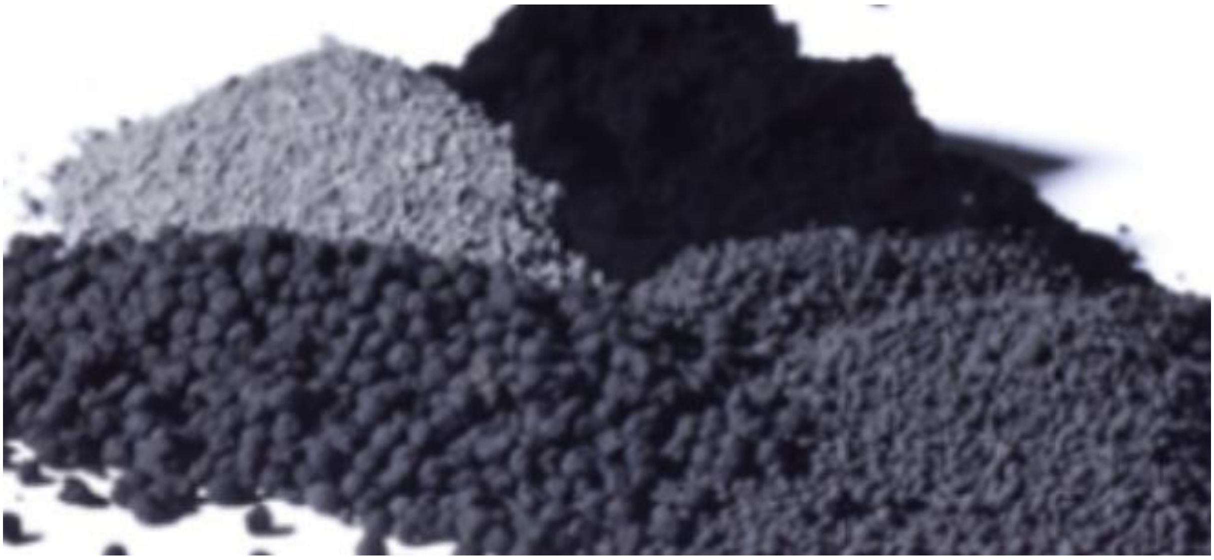

Fig:1 Carbon black in various sizes for different purposes [20]

Carbon black is commonly used as a pigment in various industries, including the rubber, plastic, and ink industries as shown in **Fig:1**. The black color of carbon black is due to its high absorption of light, which is a result of its small particle size and high surface area. The high surface area also provides carbon black with other unique properties, such as high electrical conductivity and high surface reactivity.

Carbon storage in microorganisms:

Microorganisms could store carbon dioxide (CO2), which has important implications for mitigating climate change[6]. Carbon dioxide is a potent greenhouse gas and controlling its emissions and mitigating its effects on the environment are critical priorities. Microorganisms offer a promising way to reduce atmospheric CO2 levels by sequestering it in a variety of ways.

One way in which microorganisms store carbon dioxide is through photosynthesis, where plants and algae use sunlight, CO2, and water to produce energy and store carbon in the form of sugars[7]. Photosynthetic microorganisms play a crucial role in reducing atmospheric CO2 levels, as they take in carbon dioxide from the atmosphere and store it in their cells. This carbon storage can last for long periods of time, as the carbon remains in the plant or algal biomass. Microorganisms store carbon dioxide through carbon fixation, a process in which atmospheric CO2 is converted into organic compounds by certain microorganisms. These organic compounds can then be stored in the microorganisms, where they serve as a long-term carbon sink.

Microbes such as algae, bacteria, and fungi can also store carbon dioxide by producing extracellular polymeric substances (EPS), which are complex mixtures of polysaccharides and proteins. EPSs are often produced by microorganisms in response to environmental stress, such as nutrient limitation or high levels of CO2. These EPSs can form stable structures, such as biofilms, which can sequester carbon for long periods of time.

Microorganisms can store carbon dioxide through the production of biomass, such as plant material and microorganisms themselves. Biomass can be stored in landfills, where it is decomposed over time, releasing CO2 into the atmosphere. However, this process can be slowed by proper management, such as covering the landfill with an impermeable cap or adding a layer of carbon-rich material to the top, which can serve as a sink for atmospheric CO2.

Microorganisms play a key role in storing carbon dioxide, which is an important strategy for mitigating climate change. By utilizing microorganisms for carbon sequestration, we can reduce atmospheric CO2 levels and help mitigate the negative impacts of climate change [8]. Further research is needed to better understand the mechanisms by which microorganisms store carbon dioxide and to develop new technologies for harnessing their potential for carbon sequestration.

Reuse of Carbon stored in microbes:

Carbon stored in microbes can be reused in various ways to reduce the amount of carbon dioxide released into the atmosphere, thereby reducing its impact on the environment. One way to reuse carbon stored in microbes is through the process of anaerobic digestion.

Anaerobic digestion is a biological process that occurs in the absence of oxygen, and it is commonly used for the treatment of organic waste, such as food and agricultural waste, sewage sludge, and livestock manure[9]. In this process, microbes break down the organic matter and release biogas, which is primarily composed of methane and carbon dioxide. The biogas can be recovered and burned as a renewable energy source, which not only reduces the amount of carbon dioxide released into the atmosphere but also generates electricity and heat.

Ways to reuse carbon stored in microbes is through the process of composting. Composting is the biological decomposition of organic matter, such as yard waste, food scraps, and agricultural waste, by microbes[10]. During this process, the microbes break down the organic matter and release carbon dioxide and other gases, such as methane and nitrogen. The resulting compost can be used as a soil amendment, which helps to improve the soil structure, fertility, and water retention capacity, thereby enhancing plant growth and reducing the need for chemical fertilizers and pesticides.

Additionally, carbon stored in microbes can also be used to produce biofuels. Biofuels are fuels derived from biomass, such as crops, algae, and waste, and they can be used as a replacement for fossil fuels, such as gasoline and diesel[11]. Microbes, such as yeast and bacteria, can be used to ferment the sugars and starches present in the biomass and produce biofuels, such as ethanol and biodiesel. This not only reduces the amount of carbon dioxide released into the atmosphere but also provides a renewable energy source that can help to reduce our dependence on finite and polluting fossil fuels.

There are various ways to reuse carbon stored in microbes, such as through the processes of anaerobic digestion, composting, and biofuel production. These processes not only reduce the amount of carbon dioxide released into the atmosphere but also provide numerous environmental and economic benefits, such as the generation of renewable energy, the improvement of soil fertility, and the reduction of our dependence on fossil fuels.

Color and state of carbon stored in microbes:

Carbon stored in microbes through the process of anaerobic digestion is a promising method for reducing greenhouse gas emissions and mitigating the effects of climate change. This process occurs when microorganisms break down organic matter in the absence of oxygen, producing biogas that contains methane, carbon dioxide, and other gases. While the biogas produced through this process has the potential to be used as a renewable energy source, the carbon stored in microbes through anaerobic digestion also has the potential to be reused[12].

The color of the carbon stored in microbes through anaerobic digestion varies depending on the type of organic matter that is being broken down. If the organic matter is primarily composed of plant material, the carbon stored in microbes will be green in color. However, if the organic matter is composed of animal waste or food waste, the color of the carbon stored in microbes may be brown or black. Regardless of the color, the carbon stored in microbes through anaerobic digestion is a valuable resource that can be reused in a variety of ways.

One way to reuse the carbon stored in microbes through anaerobic digestion is to use the biogas produced in the process as a renewable energy source. Biogas can be burned to generate electricity, heat, and other forms of energy, reducing the need for non-renewable sources of energy and reducing greenhouse gas emissions. Additionally, the carbon dioxide produced during anaerobic digestion can be captured and stored, reducing its impact on the environment.

Reusing the carbon stored in microbes through anaerobic digestion is through the production of biofertilizers. Biofertilizers are organic fertilizers that are produced through the process of anaerobic digestion, and they contain high levels of nitrogen, phosphorus, and other nutrients that are essential for plant growth[13]. These biofertilizers are an environmentally friendly alternative to traditional chemical fertilizers, as they are free of harmful chemicals and are biodegradable.

Finally, the carbon stored in microbes through anaerobic digestion can also be used to produce bio-based products, such as biofuels, biodegradable plastics, and other materials. These bio-based products are produced through the process of biotechnology, and they have the potential to replace traditional petroleum-based products, reducing greenhouse gas emissions and mitigating the effects of climate change.

The carbon stored in microbes through anaerobic digestion is a valuable resource that can be reused in a variety of ways. From renewable energy to biofertilizers to bio-based products, the carbon stored in microbes through this process has the potential to play a significant role in reducing greenhouse gas emissions and mitigating the effects of climate change. It is important for researchers and policymakers to continue to explore and develop new and innovative ways to reuse the carbon stored in microbes, in order to help mitigate the effects of climate change and create a more sustainable future.

Phase Change Principle:

Phase change is a physical process where a substance changes from one state of matter to another, caused by changes in temperature and/or pressure. The three main types of phase changes are melting, evaporation, and sublimation. The heat of fusion or vaporization is the amount of energy required for a substance to change from one state to another. This principle is applied in heat exchangers, thermal energy storage systems, and phase change cooling systems, which rely on absorbing and releasing heat to maintain a constant temperature or store energy. Understanding the phase change principle can help engineers and scientists design more efficient and effective systems for storing and transferring heat [15, 16].

Gas-Solid (Condensation):

Gas-solid phase change occurs when a gas cools and changes into a solid, and the principle behind this change is the heat of condensation [14,16]. This principle has several applications, including refrigeration and air conditioning systems, production of snow and ice, and production of polymers and plastics. In refrigeration systems, gas is compressed, cooled, and changed into a liquid, which then evaporates to absorb heat and cool the air. In the production of snow and ice, water vapor is cooled to change into a solid, and in the production of polymers and plastics, vaporized monomers are cooled and condensed to form a solid material that can be molded and shaped.

Liquid-Solid (Freezing):

The liquid-solid phase change occurs when a liquid cools and changes into a solid due to the energy required for this transition, known as the heat of fusion. This principle is used in refrigeration and air conditioning systems, as well as in the production of ice [15,16]. Additionally, it is utilized in material science to produce materials with specific thermal properties, such as phase change materials (PCMs) that store and release heat when changing from a solid to a liquid and vice versa, making them useful for insulation, energy storage, and thermal management applications.

Gas-Liquid (Condensation):

The gas-liquid phase change is the process in which a gas cools and changes into a liquid, and it is governed by the heat of vaporization. This principle is used in refrigeration and air conditioning systems to maintain constant temperatures in enclosed spaces, as well as in meteorology to study cloud formation and gain insights into the dynamics of the atmosphere [15]. In material science, phase change materials (PCMs) are used to produce materials with specific thermal properties, such as insulation, energy storage, and thermal management.

Solid-Liquid (Melting):

The solid-liquid phase change occurs when a solid is heated and changes into a liquid, and the energy required for this change is called the heat of fusion. This principle has important applications in refrigeration and air conditioning, food processing, and heating and cooling systems, such as the use of PCMs to store and release heat to improve energy efficiency [14]. Freezing food also uses the solid-liquid phase change to slow down bacterial growth and extend shelf life.

Solid-Gas (Sublimation):

Solid-gas phase change occurs when a solid is heated and changes into a gas, and is based on the heat of sublimation, which is the amount of energy required to change a solid into a gas. This principle is important in various applications such as refrigeration, air conditioning, food processing, and thermal energy storage systems. For example, in refrigeration systems, heat is absorbed and released as the refrigerant changes from a solid to a gas and back again, and in food processing, freeze-drying systems are used to preserve food by removing water content while maintaining its original properties. In thermal energy storage systems, phase change materials are used to store and release large amounts of heat, improving the efficiency of heating and cooling systems and reducing energy costs [14].

Dye Formulation:

A dye is a substance that imparts color to other materials. Dyes are usually soluble in water or organic solvents and can be applied to a variety of materials, including textiles, paper, leather, and even food. The global color consumption is increasing day to day. **Fig:2** shows the region-to-region variation in color usage. Dyes can be organic or inorganic, and the choice of dye depends on the material being dyed and the desired result. Dyes are used for a wide range of purposes, including coloring clothing and textiles, adding color to food and cosmetics, and for medical and scientific applications such as staining tissues for microscopic examination. The process of applying dyes to materials is called dyeing, and the resulting color is often referred to as a dye lot.

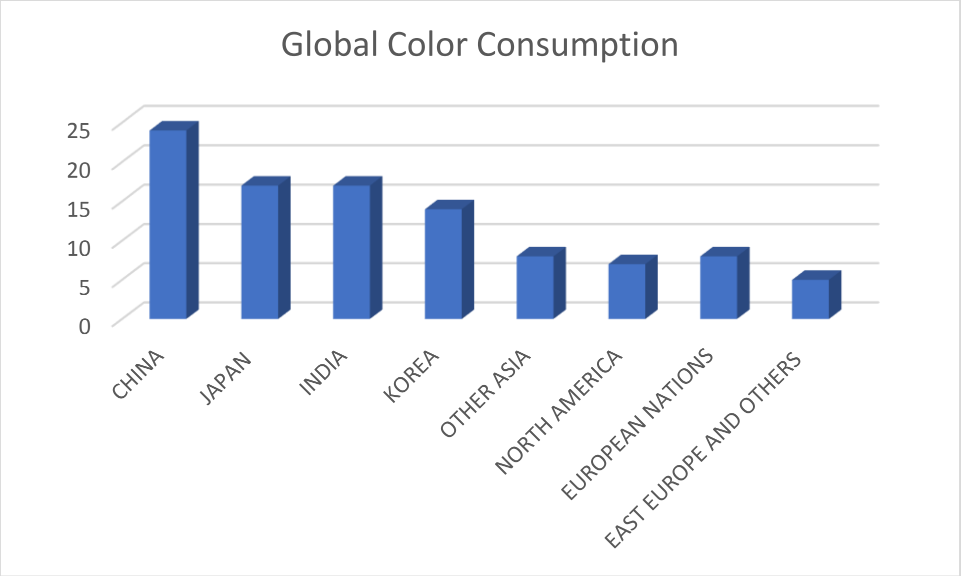

Fig:2 Global Color Consumption

Manufacturing of Dyes:

The manufacturing of dyes involves a series of chemical reactions and processes, which can vary depending on the type of dye being produced[17]. Here is a general overview of the process:

Raw material preparation: The first step in the manufacture of dyes is the preparation of the raw materials. This can involve sourcing the chemicals and pigments needed for the synthesis of the dye.

Synthesis: In this step, the raw materials are combined to form the dye molecule through a series of chemical reactions. The specific reaction pathways and conditions depend on the type of dye being synthesized[16].

Purification: Once the dye is synthesized, it must be purified to remove impurities and improve its stability and solubility. This can be done through a variety of methods, including distillation, crystallization, and filtration.

Concentration: After purification, the dye solution is usually concentrated to a desired level, either by evaporation or by adding a solvent to the solution.

Quality control: Before the dye is packaged and sold, it must undergo quality control tests to ensure that it meets the specified standards for color, stability, and performance.

Packaging and shipping: Finally, the dye is packaged and shipped to customers for use in various applications.

Microbial Fermentation for Dye preparation:

Making dyes from carbon stored in microbes involves a process called microbial fermentation. In this process, microorganisms such as bacteria or fungi are grown in a culture media that contains carbon sources such as sugars or starches. During the growth process, the microorganisms produce pigments that can be used as dyes [18]. The following is a general outline of the process:

Microbial strain selection: The first step is to select a suitable microbe that can produce the desired pigment. This can be done through screening of different microbial strains or through genetic engineering of a known strain to enhance pigment production.

Culture media preparation: The next step is to prepare a suitable culture media for growing the microorganisms. The media should contain the necessary nutrients and carbon source for optimal growth and pigment production.

Microbial cultivation: The microorganisms are then cultured in the prepared media, usually in a controlled environment such as a fermenter, where temperature, pH, and other conditions can be regulated. During the growth process, the microbes produce the desired pigment.

Harvest and pigment extraction: Once the microorganisms have reached a suitable stage of growth, the culture is harvested, and the pigment is extracted from the cells. This can be done through a variety of methods, such as filtration, centrifugation, or solvent extraction.

Pigment purification: The extracted pigment must then be purified to remove any impurities and improve its stability and solubility. This can be done through a variety of methods, such as distillation, crystallization, or chromatography.

Pigment formulation: Finally, the purified pigment is formulated into a form suitable for use as a dye, such as a solution or powder [19].

Proposed method:

Colors can be manufactured by mitigating the pollution, using basic principles and by finding the simplest way other than the present day complex techniques. **Fig:3**shows the schematic for the new proposed way of manufacturing the colors by phase change principle and in a simplest wayand simultaneously mitigating the pollution by reusing the stored carbon in the microbes.

Step:1 Anaerobic digestion helps in storing the carbon in microbes as starch or glucose. Depending on the organic matter, the color of starch is decided. If it is plant material, color could be green and if it is animal or food waste, color could be black.

Step:2 Extracting the starch or glucose pigment for formulation.

Step:3 After the formulation, phase change principle is applied. If the pigment extracted is in gas or liquid, it is converted into solid by temperature variation (decrease).

Step:4 The solidified color pigment can be crushed/powdered into fine particles into various sizes.

Step:5 The particle size defines its usage for various purposes.

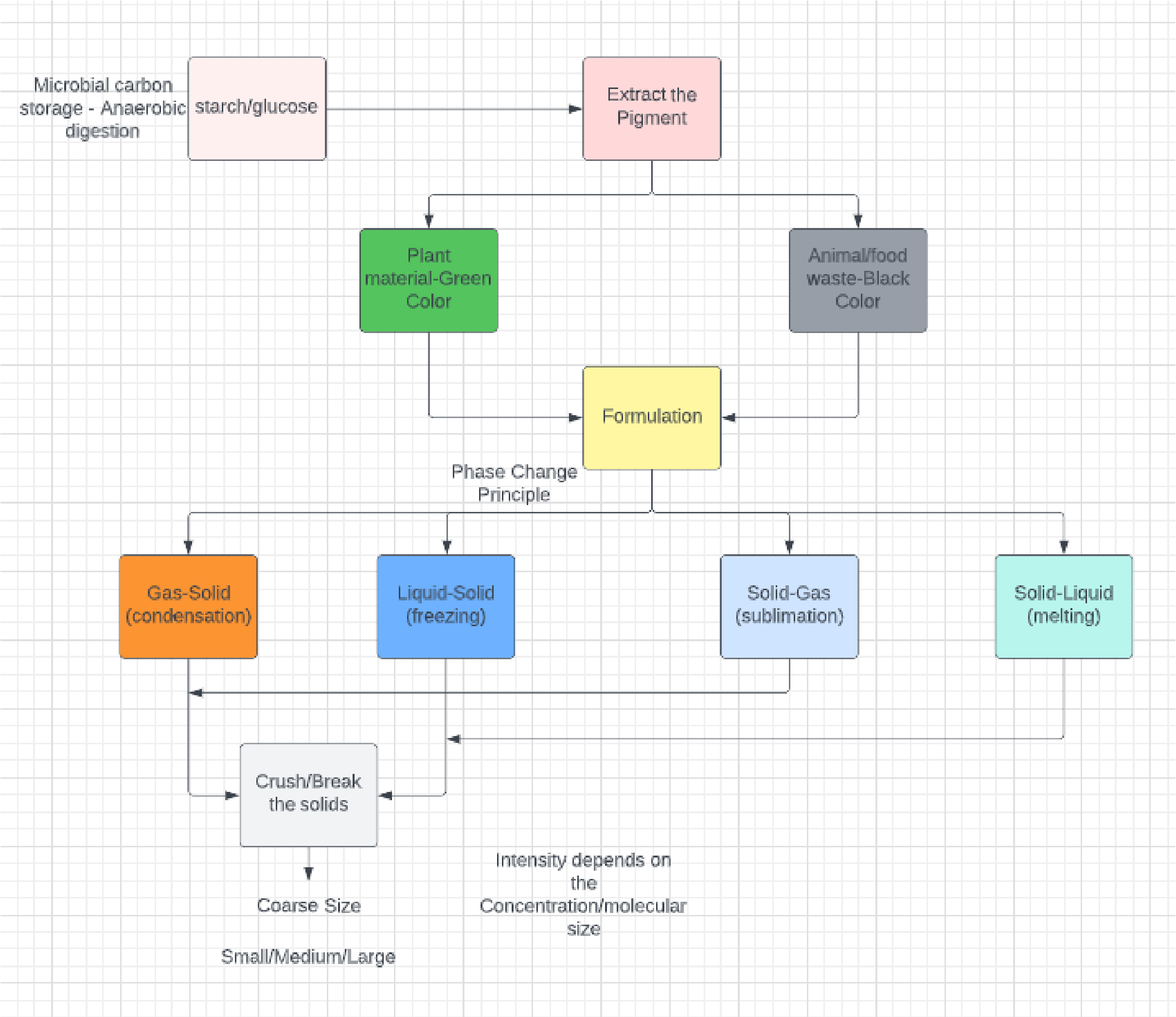

Fig:3 Schematic for the process of color manufacturing from microbial carbon storage

II. Conclusion:

It is important to note that the manufacture of dyes is a complex process that requires specialized knowledge of chemistry and expertise in chemical synthesis and purification. The specific steps and conditions used in the manufacture of dyes may vary depending on the type of dye and the desired result.Whether it's dyeing, pigment production, printing, or color filters, each method has its unique strengths and limitations, making it important to choose the right method for a particular application.Hence, usage of phase change principle would be a better way to manufacture the desired colors in desired proportions by changing the temperature, concentration and coarse size.Coarse size defines the applications for paints, rubbers, and pigments.

References:

[1]. Kant, R. (2011). Textile dyeing industry an environmental hazard.

[2]. Amal, A. M., Abeer, K. A., Samia, H. M., Nadia, A. E. N. H., KA, A., & HM, E. H. (2011). Selection of Pigment (Melanin) production in Streptomyces and their application in Printing and Dyeing of Wool Fabrics. Research Journal of Chemical Sciences

[3]. Nguyen, H. A. D., Lee, C., Shin, K. H., & Lee, D. (2015). An investigation of the ink-transfer mechanism during the printing phase of high-resolution roll-to-roll gravure printing. IEEE Transactions on Components, Packaging and Manufacturing Technology, 5(10), 1516-1524.

[4]. Mahani, F. F., & Mokhtari, A. (2018). TiO2 circular nano-gratings as anti-reflective coatings and potential color filters for efficient organic solar cells. Journal of nanoelectronics and optoelectronics, 13(11), 1624-1629.

[5]. International Agency for Research on Cancer (IARC). (2010). Carbon black. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, 93, 1-447. https://monographs.iarc.fr/wp-content/uploads/2018/06/mono93.pdf

[6]. Mason-Jones, K., Breidenbach, A., Dyckmans, J., Banfield, C. C., & Dippold, M. A. (2023). Intracellular carbon storage by microorganisms is an overlooked pathway of biomass growth. Nature Communications, 14(1), 2240.

[7]. Vecchi, V., Barera, S., Bassi, R., & Dall'Osto, L. (2020). Potential and challenges of improving photosynthesis in algae. Plants, 9(1), 67.

[8]. Kheirfam, H. (2020). Increasing soil potential for carbon sequestration using microbes from biological soil crusts. Journal of Arid Environments, 172, 104022.

[9]. Angelidaki, I., Ellegaard, L., & Ahring, B. K. (2003). Applications of the anaerobic digestion process. Biomethanation ii, 1-33.

[10]. Sitterley, K. A., Silverstein, J., Rosenblum, J., & Linden, K. G. (2021). Aerobic biological degradation of organic matter and fracturing fluid additives in high salinity hydraulic fracturing wastewaters. Science of The Total Environment, 758, 143622.

[11]. Pourhashem, G., Adler, P. R., & Spatari, S. (2016). Time effects of climate change mitigation strategies for second generation biofuels and co-products with temporary carbon storage. Journal of Cleaner Production, 112, 2642-2653.

[12]. Osman, A. I., Fawzy, S., Farghali, M., El-Azazy, M., Elgarahy, A. M., Fahim, R. A., ... & Rooney, D. W. (2022). Biochar for agronomy, animal farming, anaerobic digestion, composting, water treatment, soil remediation, construction, energy storage, and carbon sequestration: a review. Environmental Chemistry Letters, 20(4), 2385-2485.

[13]. Yilmaz, E., & Sönmez, M. (2017). The role of organic/bio–fertilizer amendment on aggregate stability and organic carbon content in different aggregate scales. Soil and Tillage Research, 168, 118-124.

[14]. Wei, G., Wang, G., Xu, C., Ju, X., Xing, L., Du, X., & Yang, Y. (2018). Selection principles and thermophysical properties of high temperature phase change materials for thermal energy storage: A review. Renewable and Sustainable Energy Reviews, 81, 1771-1786.

[15]. Zhang, S., Shen, Y., Wang, L., Chen, J., & Lu, Y. (2019). Phase change solvents for post-combustion CO2 capture: Principle, advances, and challenges. Applied energy, 239, 876-897.

[16]. Jang, S. H., Lee, G., Lee, S. Y., Kim, S. H., Lee, W., Jung, J. W., ... & Choi, J. (2022). Synthesis and characterisation of triphenylmethine dyes for colour conversion layer of the virtual and augmented reality display. Dyes and Pigments, 204, 110419.

[17]. Freeman, H. S., & Mock, G. N. (2012). Dye application, manufacture of dye intermediates and dyes. Handbook of industrial chemistry and biotechnology, 475-548.

[18]. Ren, Y., Gong, J., Fu, R., Li, Z., Li, Q., Zhang, J., ... & Cheng, X. (2017). Dyeing and antibacterial properties of cotton dyed with prodigiosins nanomicelles produced by microbial fermentation. Dyes and Pigments, 138, 147-153.

[19]. Singh, S., Adeyemi, K. T., & Vernwal, S. (2022). Adsorption-microbial fermentation based multi-step approach to dye remediation for safe and environment compatible wastewater treatment. Environmental Challenges, 7, 100459.

[20]. Orion Engineered Carbons. (n.d.). Orioncarbons.com. Retrieved May 12, 2023, from https://orioncarbons.com/what_is_carbon_black.

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