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### RESEARCH ARTICLE

#### BIO-MITIGATION STUDIES OF ARTIFICIAL SWEETENER IN WASTE WATER: A REVIEW

Sourav Paul<sup>1</sup>, Bishal Das<sup>1</sup>, Deepika Biswas<sup>1</sup>, Ayesha Zafar<sup>1</sup>, Sayanee Sarkar<sup>2</sup> and Jigisha Roy Panda<sup>2</sup>

1. Guru Nanak Institute Pharmaceutical of Science and Technology, Department of Life Science.
2. 157/F, Nilgunj Road, Sahid Colony, Panihati, Khardaha, Kolkata - 700114, West Bengal, India.

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#### Abstract

Artificial sweeteners, which are widely used in modern diets and are persistent and may have negative effects on aquatic ecosystems, such as saccharin (SAC), cyclamate (CYC), aspartame (ASP), acesulfame (ACE), sucralose (SUC), alitame (ALT), neotame (NEO), and neohesperidin dihydrochalcone (NSDH), are being found in wastewater effluents at an increasing rate. In order to address this problem, bio-mitigation studies have shown promise as a method of reducing the harm that wastewater-borne artificial sweeteners do to the environment. This review provides a comprehensive overview of recent advancements in bio-mitigation approaches for artificial sweeteners in wastewater treatment systems. Firstly, the prevalence and persistence of artificial sweeteners in wastewater are discussed, highlighting their widespread occurrence and challenges associated with their removal during conventional wastewater treatment processes. Subsequently, various bio-mitigation strategies are examined, including microbial degradation, phytoremediation, and advanced oxidation processes. Microbial degradation, facilitated by diverse microbial communities, has shown potential for degrading artificial sweeteners into less harmful byproducts. Several other techniques like Photocatalytic Degradation, Bank filtration, Granular activated carbon (GAC), advanced oxidation processes, such as ozonation and UV/H<sub>2</sub>O<sub>2</sub> treatment, are explored for their ability to degrade artificial sweeteners into non-toxic compounds.

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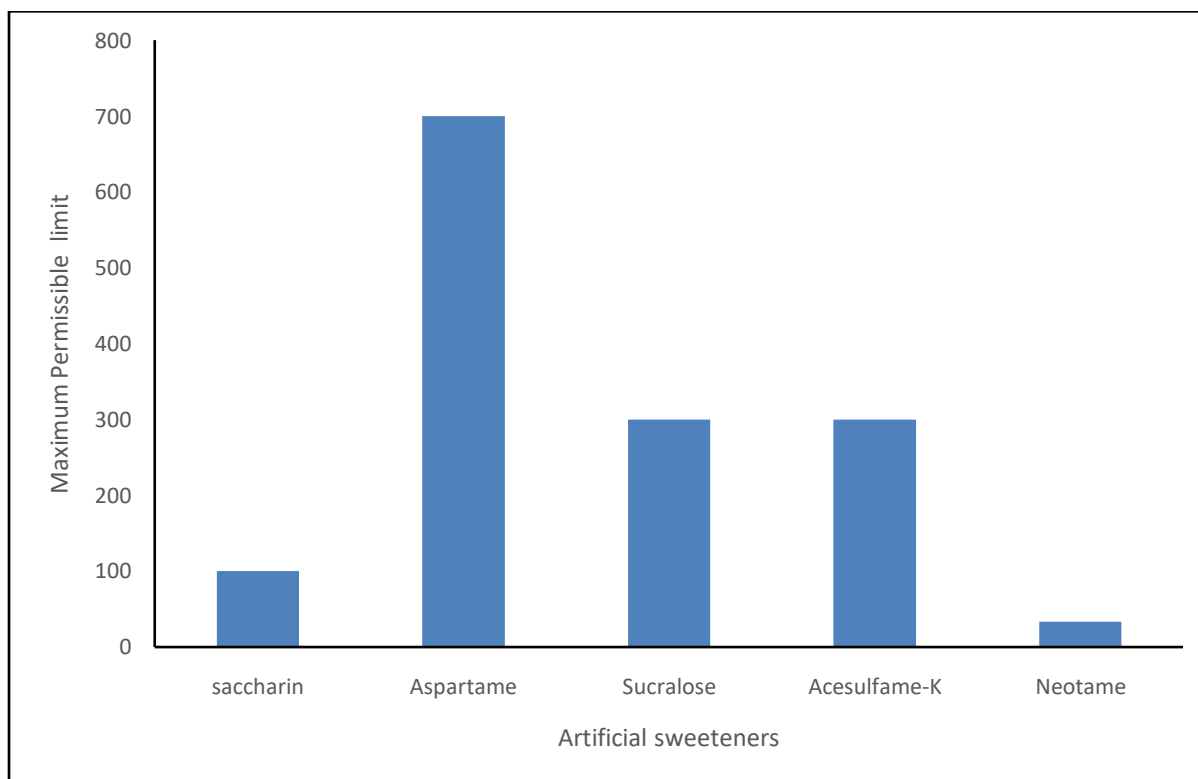
#### Introduction:-

The food industry, with its extensive use of additives and artificial sweeteners, is one of the contributors to this growing pollution problem. Artificial sweeteners, commonly used as sugar substitutes in a various range of food, beverage products, have been popular due to their less calorie content and provide intense sweetness (Chattopadhyay et al., 2014). However, their widespread use has led to their presence in water bodies, making them an emerging food industry-based pollutant in aquatic environments (Naidu et al., 2016). Artificial sweeteners, such as SAC, ASP, SUC, CYC, NEO, NSDH, ALT (figure 1) this all are designed to resist natural degradation processes, resulting in their persistence in water sources (Naik et al., 2021). Conventional remediation approaches are frequently ineffective at eliminating these compounds, causing to their accumulation in the environment. This accumulation raises concerns about the possible ecological and human health consequences with longterm exposure to artificial sweeteners (Lamb et al., 2019). Artificial sweeteners are mostly employed in the food sector to process lowcalorie foods and beverages

**Corresponding Author:- Dr. Jigisha Roy Panda**

Address:- Assistant Professor, Guru Nanak Institute of Pharmaceutical Science and Technology.

that do not contain sugar. They are basically use in human diets because they do not affect inglycaemic or insulin response upon ingestion(Chattopadhyay et al., 2014). Furthermore, they do not contribute to calorie intake and do not negatively impact dental plaque microflora, distinguishing them from sugar. Among sulfamates, CYC is now the most advanced artificial sweetener, closely followed by SAC. ASP and ACE-K are well-known brands in the diet soft drink sector, while SUC continues to control the principal market for sweeteners (Suez et al., 2014). Emerging pollutants or emerging contaminants are pollutants that have been present in the environment for a long time but have not undergone a thorough examination of their presence, environmental behaviour, and toxicity assessment, or are not currently regulated by global standards. Artificial sweetenersfit under newly discovered class of environmental contaminants due to their extensive distribution and widespread occurrence in diverse aquatic ecosystems(Naidu et al., 2016).



**Figure 1:-** Maximum permissible limits of various artificial sweeteners.

#### **Effect of artificial sweeteners in human health and environment:**

Artificial sweeteners have been found as having adverse impact both in humans and aquatic organisms. Their health impacts were not previously recognized because lack of the standards and guidelines for their environmental monitoring. Only recently have they been acknowledged as potential environmental contaminants(Miraji et al., 2016). The initial detection of artificial sweeteners was observed in both water and soil (Suez et al., 2014).A considerable fraction of these artificial sweeteners was discovered to survive without significant modifications and had poor absorption. The ASs discharged from various sources enter wastewater treatment plants (WWTPs). Despite the efficiency of many WWTPs, a significant amount of ASs tends to escape treatment. Treated effluents from these WWTPs are regard important point sources of AS, resulting to their release into the environment (N. H. Tran et al., 2014).In the aquatic environment, the main metabolites of ASP, NEO, ALT, and NSHD are expected to be present rather than their parent compounds (table 1). SAC, one of the oldest artificial sweeteners, has been commercially produced since 1878. Once consumed, SAC is not metabolised by the body and is eliminated unaltered in urine. The unabsorbed fraction is removed by faces. (Osin et al. 2018). SAC has been found in groundwater, with variety of sources including the application of fertilizers in agriculture, the breakdown of sulfonylurea herbicides, historical landfills, irrigation techniques, soil water management,sludge fertilizer usage, and duct leaks. Additionally, municipal effluent and sewage have been discovered to contain SACit's also used in various industry, albeit in smaller amounts, specifically as a galvanic brightener. In coastal and sea waters, SUC has been detected. Notably, surface waters in China have reported concentrations of SAC limit up to 0.21 µg/l(Kleinstauber et al., 2019).ASP is

an ester composed of a dipeptide of l-aspartyl-l-phenylalanine. In certain food items, particularly those that have been kept for long periods such as carbonated and still drinks, have poor stability of ASP in aqueous media is unsatisfactory. As a dipeptide ester, ASP is susceptible to both hydrolysis and cyclization reactions process. Under acidic circumstances, the hydrolysis of the ester and amide bonds is preferred, resulting in the synthesis of its constituent amino acids while also reducing of sweetness. More neutral and alkaline are promote to the cyclization of ASP to the equivalent diketopiperazine(Luo et al., 2019).

**Table 1:-** Maximum permissible limits of mostly used artificial sweeteners.

Artificial sweetener	Sample source	Maximum limit (PPM)	References
Saccharin	Soft drink, concentrate water	100	[1]
Aspartame	Soft drink, concentrate water	700	[3], [6]
Sucralose	Soft drink, concentrate water	300	[4]
Acesulfame-K	Soft drink, concentrate water	300	[2], [4]
Neotame	Soft drink, concentrate water	33	[1], [4], [5]

ASs have acquired notice as a distinct type of environmental pollutants owing to their exceptional longevity and extensive presence. The ongoing introduction of AS into aquatic environments is related to their robust nature during wastewater treatment processes. However, the behaviour, density, and long-term ecotoxicological impact of AS in water resources are still mostly understood. A study of ACE-K, CYC, SAC, and SUC in an open coast system at an estuarine/marine junction found that ACE-K (seasonal average: 0.22  $\mu\text{g L}^{-1}$ ) and SUC (0.05  $\mu\text{g L}^{-1}$ ) were more prevalent in the summer, while SAC (0.11  $\mu\text{g L}^{-1}$ ) and CYC (0.10  $\mu\text{g L}^{-1}$ ) were mostly detected in the winter This shows a substantial relationship with the varying chemical resistance of various sweeteners (Suez et al., 2014).The UPLC-ESI/MS degradation profile of ACE-K and SUC compounds revealed a considerable potential for the generation of novel photo by-products under extended UV irradiation. Photodegradation studies also showed that the phototoxicity of ACE-K compounds might possibly harm aquatic environments (Harpaz et al., 2018).

Research that assessing inputs from agriculture and households, degradation, and leaching to groundwater discovered that a considerable concentration of SAC might enter soils through liquid manure. Piglet feed contains SAC, which is mostly eliminated and can reach concentrations of up to 12 mg/l after two months of storage. SAC was also found as a soil metabolite of several sulfonylurea herbicides. AS can infiltrate soil through irrigation with wastewater-polluted surface water, fertilization with sewage sludge (1–43  $\mu\text{g/L}$ ) or by the leaking sewers. Soil incubation tests showed that CYC, SAC, ACE-K, and SUC al degrade, with half-lives ranging from 0.4 to 6 days, 3 to 12 days, 3 to 49 days, and 8 to 124 days, respectively. The study found that manure application caused the presence of SAC in groundwater (0.26  $\mu\text{g/L}$ ), indicating the significance of soil entry routes, degradation, and leaching. ACE-K concentrations (up to 5  $\mu\text{g/L}$ ) may be due to wastewater-polluted surface waters infiltrating via stream beds(Mahmoud & Abd El-Kader, 2015).

The widespread presence of artificial sweeteners in various environmental samples, as well as their effective recovery and exact measurement, is dependent on a number of external conditions. These considerations include the type of solid-phase extraction (SPE) cartridges utilised, buffer composition and pH levels, matrix effects, and the stability of the sampled material (Lei et al., 2015). Solid-Phase Extraction (SPE) in combination with Liquid Chromatography-Electrospray Ionization-Mass spectrometry is the most used method for determining artificial sweeteners. Among the ASs widely present in diver's environmental media, ACE-K and SUC concentrations were found be in the following order: WWTPs produce effluent that flows via surface water, groundwater, drinking water, atmosphere, and soil. AS levels vary significantly throughout different regions(Lei et al., 2015).Artificial sweeteners have been identified as emerging environmental contaminants and have been found in receiving waterways, including surface waters, groundwater aquifers, and drinking water.The relative toxicity of AS was studied using a bioluminescence activity experiment with E. coli derived genetically engineered bioluminescent bacteria. Toxic effects were visualized as the bacteria were exposed to certain quantities of Artificial sweeteners. The bioluminescence activity experiment revealed two unique toxicity response patterns are known as the induction and

the inhibition of the bioluminescent signal. An inhibition response pattern was observed in the reactions to SUC and NEO. Additionally, the bioluminescent bacterial panel used in the study has the potential to be employed for the detection of ASs in the environment, utilizing a specific mode-of-action pattern (Mahmoud & Abd El-Kader, 2015).

Emerging contaminants primarily originating from industrial sources and medical wastes, undergo translocation processes from soils to plants, eventually reaching consumers in the form of vegetables, fruits, etcetera, which are irrigated with either treated wastewater or untreated surface water. In addition to ASs, additional developing contaminants including steroidal estrogens, ibuprofen, bromofen, caffeine, methyl dihydrojasmonate and others. The reported pollutant levels in agricultural irrigation fluids range from 10 to 500 ng/L. Pollutant concentrations in crops range between 1 and 7500 ng/kg (Cantwell et al., 2019). Artificial sweeteners can contaminate groundwater in a variety of ways, both directly and indirectly. These channels include the percolation of treated wastewater in soil aquifer treatment, infiltration of wastewater-influenced surface water, landfill leachate, municipal wastewater reservoirs, septic systems, and the percolation of manure on agricultural land (Naik et al., 2021). Model species such as *Lemna minor*, *Sinapis alba*, *Daphnia magna*, *Enchytraeus crypticus*, *Desmodesmus subspicatus*, and *Lactuca sativa* were examined at a limit concentration of 100 mg/l for the influence of artificial sweeteners (ASP and SAC). The study found statistically significant negative impact on *Lemna minor*. Additionally, both ASP and SAC have detrimental reproductive effects on enchytraeids (Mawhinney et al., 2011).

Artificial sweeteners have been assessed as a new environmental problem, with the aquatic ecosystem suffering the brunt of these growing toxins (table 2). When consumed, a significant quantity of these sweeteners remains unaltered within the human body and finds its way into the environment (Gomes et al., 2017). They demonstrate resistance to wastewater treatment methods, resulting in their ongoing introduction into aquatic habitats. However, there is still a significant lack of research regarding to the environmental behaviour, fate, and the potential long-term ecological repercussion of artificial sweeteners in our water resource (Eriksson Wiklund et al., 2014). Artificial sweeteners may reach aquatic habitats via wastewater discharge from houses, WWTP and industrial activities (Saucedo-Vence et al., 2017). Once in the water, they can accumulate and persist, possibly affecting aquatic life. The presence of artificial sweeteners in water bodies can have direct or indirect ecological consequences on aquatic animal or plant. While the long-term ramifications are still being investigated, some possible effects include changes in eating habits, reproduction, and overall ecosystem dynamics. Artificial sweeteners can bioaccumulate in aquatic animal or organisms, such as fish and invertebrates (Luo et al., 2019). The term "bioaccumulation" describes the gradual build-up of a material in an organism's tissues. Higher up the food chain species may have greater sugar concentrations as a result of this. The natural bacteria found in aquatic habitats as well as other microbial communities can be altered by artificial sweeteners (Mailler et al., 2015). These alternation in microbial diversity may have larger ecological implications. Environmental transformation processes using AS may result in the creation of breakdown products. Compared to the parent chemicals, certain of these transformation products could be more toxic or persistent (Rostvall et al., 2018). When wastewater treatment systems attempt to remove AS, they may become resistant, which may lead to their discharge into natural waterways. Traditional treatment procedure cannot properly remove them, ca to the dissemination of these harmful compounds into the environment. Some AS are recognised for their environmental persistence, which means they may remain in water bodies for long periods of time, potentially alter the balance of these ecosystems (Gomes et al., 2017).

**Table 2:-** Comparative study of artificial sweeteners based upon their chemical composition.

Artificial sweeteners	Chemical Formula	Sweetening potential	Uses	Molar mass (g/mol)	Density (g/cm <sup>3</sup> )
ASP	C <sub>14</sub> H <sub>18</sub> N <sub>2</sub> O <sub>5</sub>	200	Food and beverage	294.3	1.347
SAC	C <sub>7</sub> H <sub>5</sub> NO <sub>3</sub>	300	Soft drinks, tabletop sweeteners	183.2	0.83
ACE	C <sub>4</sub> H <sub>4</sub> KNO <sub>4</sub> S	200	beverages, dairy products, confectionery,	163.15	1.83
NEO	C <sub>20</sub> H <sub>24</sub> N <sub>2</sub> O <sub>5</sub>	7000	Carbonated soft drinks, yogurts, cakes,	378.46	1.13
SUC	C <sub>12</sub> H <sub>19</sub> Cl <sub>3</sub> O <sub>8</sub>	6000	Diet foods and beverages	397.64	1.69
ALT	C <sub>14</sub> H <sub>25</sub> N <sub>3</sub> O <sub>4</sub> S	2000	Bakery products,	331.43	—

			snack foods,		
CYC	C <sub>6</sub> H <sub>12</sub> NNaO <sub>3</sub> S	30	Baked goods, confections, desserts, soft drinks,	201.22	0.7

AS also known as sugar replacement or non-nutritive sweeteners, are widely recognized as safe for consumption within established acceptable daily intake (ADI) levels (as per table 2). However, some person may have experience negative responses or adverse reactions to these sweeteners (Fitch et al., 2021). When taking artificial sweeteners, some people may have gastrointestinal symptoms such as gas, bloating, diarrhoea, or upset stomach. Some people have mentioned experiencing headaches or migraines after using artificial sweeteners. ASP, in particular, has been linked with this negative effect in certain cases (McKie et al., 2016). There is some dispute regarding whether the usage of AS can lead to weight gain. Some research shows that consuming AS may disrupt hunger control, resulting to increased calorie intake from other sources. Recent studies have looked at the impact of AS on the gut microbiota. While certain data show that these sweeteners may have an influence on the composition of the gut microbiota, the long-term health repercussions are yet unclear (Li et al., 2018). Emerging research has raised questions about the potential impact of artificial sweeteners on metabolic health. Some studies have suggested a link between artificial sweeteners and metabolic changes, such as alterations in glucose metabolism and insulin sensitivity. Side effects can vary widely among individuals, and most people can consume artificial sweeteners without experiencing adverse effects. Furthermore, regulatory agencies like those in the United States. The Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA) defined ADI thresholds for artificial sweeteners to assure safety (Fitch et al., 2021).

#### Photocatalytic Degradation of Artificial Sweeteners

Over the past few decades, numerous investigations have concentrated on exploring the capabilities of advanced oxidative processes (AOPs) for addressing environmental pollution, particularly in the context of treating contaminants in wastewater and industrial waters (Meyer et al., 1982). Within the category of AOPs, heterogeneous photocatalysis stands out. This process entails the transfer of electrons through concurrent oxidation and reduction reactions, triggered by sunlight or artificial light, occurring on the surface of semiconductors (Pulido Melián et al., 2016). When a semiconductor is photoactivated, a series of events are set off that result in the creation of reactive species such as singlet oxygen, hydroxyl (HO), superoxide (O<sub>2</sub><sup>-</sup>), hydroperoxyl (HO<sub>2</sub>) radicals, electrons (e<sup>-</sup>), and holes (h<sup>+</sup>). These entities work synergistically in the degradation of organic pollutants. In the photocatalysis process using TiO<sub>2</sub> under UV radiation, hydroxyl radicals play a primary role in the degradation of organic compounds in water. However, new research demonstrating the participation of other reactive species is essential to comprehending this photocatalytic process in its whole. (H. T. T. Tran et al., 2017).

A glass reactor measuring 9 cm in diameter and 14 cm in height that had water circulation and a temperature of 25°C was used for the photocatalytic process. The experiment took place with continuous magnetic stirring. Radiation for the reaction was provided by the mercury vapour lamp filament at high pressure (125 W HPL-N base E27, Philips), positioned at the centre of the reactor and enclosed by a Pyrex glass protective bulb, emitting UV-A radiation at 365 nm. The photon flux rate, equivalent to  $3.435 \times 10^{-7}$  einstein L<sup>-1</sup> s<sup>-1</sup> for UV-A radiation, was determined through uranyl-oxalate actinometry (Curcó et al., 1996). Aqueous solutions containing AS, ACE-K and SAC, were prepared with a concentration of 20 mg L<sup>-1</sup>. The pH levels were corrected using diluted HCl or NaOH solutions. In the experimental setup, 200 mL of the sweetener solution and the semiconductor TiO<sub>2</sub> were introduced into the reactor under the desired conditions, and the mixture underwent photocatalytic treatment for a duration of 60 minutes. Before exposure to radiation, the solution was continually agitated in the dark for 30 minutes to assure the sweetener's adsorption equilibrium on the TiO<sub>2</sub> surface.

#### Analytical Methods

##### Sweetener Quantification:

The degradation analysis of artificial sweeteners, with certain modifications, was carried out using an Agilent Technologies 1200 Series chromatograph equipped with a diode array detector. The chromatographic conditions employed were as follows: a photocatalyzed solution injection volume of 10 µL, a ZORBAX Eclipse column (XDB-C18, 150 × 4.6 mm, 5 µm), and a binary mobile phase with a flow rate of 0.8 mL min<sup>-1</sup>. The mobile phase composition consisted of 94% sodium phosphate monobasic (pH 7.0 adjusted with sodium hydroxide) and 6% acetonitrile (de Queiroz Pane et al., 2015). The isocratic elution method was used to carry out the chromatographic

process. Specific wavelengths were used for detection; at 201 nm, sodium saccharin and at 227 nm, acesulfame potassium were found. The limit of detection for both sweeteners was determined to be  $0.04 \text{ mg mL}^{-1}$ , while the quantification limits were  $0.15 \text{ mg mL}^{-1}$  for ACE-K and  $0.13 \text{ mg mL}^{-1}$  for SAC (Zelinski et al., 2018).

#### **Total Organic Carbon Analysis:**

A Shimadzu TOC-VCPH carbon analyser was used to evaluate the photocatalytic process' effectiveness in terms of the mineralization of AS Samples that had been photocatalyzed were filtered, acidified with sulfuric acid, and then examined. This methodology uses an indirect method in which the difference between the contents of total carbon (TC) and inorganic carbon (IC) is used to calculate the concentration of total organic carbon (TOC) (Pulido Melián et al., 2016).

#### **Acute Toxicity Analysis:**

To evaluate the ACE-K and SAC aqueous solutions acute toxicity both before and after photocatalytic treatment, experiments were conducted using the microcrustacean *Artemia salina* (de Queiroz Pane et al., 2015). In this assay, a hatching medium and microcrustacean culture were prepared using a distilled water and sea salt solution ( $30 \text{ g/L}^{-1}$ , pH 9.0). *Artemia salina* cysts that had been dehydrated were placed in the saline solution to hatch, and they were kept in the dark at a temperature that was kept at a constant  $28^\circ\text{C}$  (Meyer et al., 1982).

After 24 hours, any unhatched cysts were removed, and the nauplii were kept under the same conditions for an additional 24 hours. The nauplii at 48 hours of life were collected at the end of this cycle and included to the tests and controls. Comparing the nauplii to the saline solution, which served as the negative control, the diluted sodium dodecyl sulphate (SDS) positive control, and the ACE-K and SAC samples, both with and without treatment, at concentrations of 10, 100, 250, 500, and 1000 mg/L were all part of the evaluation process. Ten nauplii and approximately 2.5 mL of each sample were placed in Eppendorf tubes. These tubes were then incubated in an oven set to a temperature range of  $27\text{--}30^\circ\text{C}$  for 48 hours. The number of immobile nauplii was recorded at both the midpoint and the end of the established exposure time.

### **Results and Discussion:-**

#### **Effects of pH and Photocatalyst Mass on Photocatalytic Degradation:**

A factorial planning design  $2^2$  was used to investigate the effects of pH and photocatalyst ( $\text{TiO}_2$ ) mass on the degradation of ACE-K and SAC. The breakdown of SAC and ACE-K at 2.5 and 15 minutes, respectively, was used to establish the response variable. With this method, the combined effects of altering photocatalyst concentrations and pH levels on the degradation process may be systematically explored. It's also found that when the pH changed from acidic to alkaline, the degradation of ACE-K and SAC showed an average increase of 9% and 2.5%, respectively (Lin et al., 2016).

Reviewed the photocatalyst mass, ACE-K degradation increase by 3% whereas SAC degradation dropped by 8.5% when the  $\text{TiO}_2$  mass increased from 250 to  $500 \text{ mg/L}^{-1}$ . The differences for ACE-K ( $\pm 2.10$ ) and SAC ( $\pm 2.60$ ) at the centre point indicate that pH has a bigger impact on ACE-K degradation than photocatalyst mass (Zelinski et al., 2018). The effect of pH is difficult to interpret as it involves electrostatic interactions between the  $\text{TiO}_2$  surface and other species participating in the photocatalytic process. Due to differences in surface charge, any pH change—whether greater or lower than the isoelectric point of  $\text{TiO}_2$  (pH 6.25) affects the adsorption of molecules on the surface of the photocatalyst. The surface of the photocatalyst becomes positively charged when it is in an acidic liquid (pH < 6.25) (H. T. T. Tran et al., 2017). In contrast an alkaline medium (pH > 6.25) deprotonation occurs, resulting in a net negative charge. These changes in the surface charge affect the total performance of the photocatalytic process (Cavalcante et al., 2016).

Although protonation of the photocatalyst surface is expected to boost adsorption for anionic organic salts such as ACE-K and SAC, the current study's results show that deprotonation instead promoted adsorption. Adsorption is more difficult in an alkaline solution because the anionic chemicals' negative charges repel the photocatalyst. Nonetheless, in an alkaline media, the photocatalyst's surface has more hydroxyl ions available, which encourages the production of hydroxyl radicals and raises the process's overall efficiency. Considering the rise in photocatalyst mass, it's noteworthy that both ACE-K and SAC belong to the sulphonamides class, yet they exhibit distinct behaviours. The observed decrease in the degradation of SAC can be attributed to the presence of an aromatic ring in its molecular structure. Aromatics tend to behave in a recalcitrant manner, leading to a slower photocatalytic

degradation that necessitates prolonged irradiation times. The aromatic nature of SAC contributes to its reduced reactivity during the photocatalytic process compared to ACE-K (Punturat & Huang, 2016).

#### **Some other typical approaches for efficient Artificial Sweeteners removal:**

As highlighted earlier, the public has gradually recognized the negative impacts and ecotoxicity associated with AS. To mitigate their side effects, it is imperative to develop effective approaches for the removal and degradation of ASs. These trace emergent organic pollutants may be effectively removed using a variety of techniques, which can be roughly categorised into physical, chemical, and biological processes.

#### **Bank filtration:**

The main method that physical removal pathways use adsorptive effects are by adsorbents, bank/sand filtration, etc. In instance, bank filtration is a naturally occurring attenuation mechanism that keeps AS by using the adsorptive qualities of soils. According to reports, bank filtration can efficiently remove CYC and SAC, up to approximately 100%, even with short retention periods of 12 days. Because AS are so hydrophilic and extremely water soluble, it is hypothesised that they will have a low soil adsorption propensity. Consequently, it could be dubious to depend exclusively on adsorptive effects for the elimination of AS (Kattel et al., 2017).

#### **Granular activated carbon (GAC):**

GAC has found extensive use in water treatment facilities for the adsorption of water contaminants. The performance of GAC in removing artificial sweeteners (ASs) has been subject to review (Mailler et al., 2015). Among the frequently detected artificial sweeteners (ASs) in aquatic environments, such as ACE, CYC, SAC, and SUC, SAC and SUC are the most likely to be removed by granular activated carbon (GAC) filtration. For instance, there has been a significant reduction in the concentration of SUC, decreasing from  $11 \pm 3.2$  to  $0.03 \pm 0.0$   $\mu\text{g/L}$  through GAC filtration (Rostvall et al., 2018). It has been observed that a full-scale GAC filter can effectively remove up to 54% of SAC and 26% of SUC, highlighting the filtration efficiency of GAC for these artificial sweeteners (Nam et al. 2018). Furthermore, it was indicated that the adsorption capacity of GAC for AS followed the order of SAC > SUC > CYC > ACE (Zelinski et al., 2018).

#### **Resins:**

Resins have been employed for the removal of AS and have demonstrated superior performance compared to GAC. According to studies, while utilising the same load levels, resin adsorbents for ASs had an adsorptive capacity  $3.33 \pm 18.51$  times greater than GAC, with the exception of absorbing SUC. SAC > ACE > CYC > SUC was the sequence in which the resin's saturation adsorption occurred. Saturation data showed that the elimination of ASs for ACE was 79.54%, CYC was 31.9%, and SAC was 8.1%. The pKa values of the substances and these results agreed. One possible explanation for SUC's restricted resin adsorption is that it has a low ionising potential (Li et al., 2018).

#### **Other physical techniques:**

While sorbents have been employed for the removal of AS, their efficiency in the removal was found to be much lower compared to GAC (Ghosh et al., 2018). The combination of sedimentation and coagulation has been recommended at times for the removal of micropollutants in wastewater. However, the performance of this approach was not satisfactory for hydrophilic AS, and these hydrophilic ASs could be overlooked in the wastewater treatment processes (Ma et al., 2017b).

#### **Ultraviolet light (UV):**

There is nothing that UV light can do to completely remove AS, especially ACE and SUC. According to reports, only ACE would be degraded by UV in clean and natural waters. After five hours of UV exposure, table 3 shows that ACE degraded by around 35%, whereas SUC did not decay at all. It was reviewed that only 17% ACE was degraded by UV after evaluating four AS: SUC, ACE, SAC, and CYC. (Kattel et al., 2017). This result can be explained by the fact that SUC, SAC, and CYC have low molar extinction coefficients, whereas ACE can directly photolyze in the UV area (Ma et al. 2017). UV exposure is typically combined with advanced oxidation processes assisted by  $\text{H}_2\text{O}_2$  and other catalysts (Zelinski et al., 2018).

The degradation efficiency of artificial sweeteners (ASs) was investigated using UV/ $\text{H}_2\text{O}_2$  and UV/ $\text{S}_2\text{O}_8^{2-}$  processes. The reaction constants were in the following order: ACE > CYC > SAC > SUC, and both processes had pseudo-first-order kinetics. SUC had the slowest rate of reaction, whereas ACE and CYC preferred to react with  $\text{SO}_4$  and OH. UV/ $\text{S}_2\text{O}_8^{2-}$  outperformed UV/ $\text{H}_2\text{O}_2$  at the same dose for AS degradation due to its larger redox potential

(~3.10 V) and superior selectivity for organic molecules (Ghosh et al., 2018). The photocatalytic degradation by UV/S<sub>2</sub>O<sub>8</sub><sup>2-</sup> should also be correlated with the initial concentration of AS, pH value, S<sub>2</sub>O<sub>8</sub><sup>2-</sup> concentration, and the content of natural organic matter (Tran et al. 2015). According to a recent study, solar simulators might be used to photo catalytically degrade ACE. The degradation efficiency was positively correlated with the photocatalyst dosage (TiO<sub>2</sub>) and solar light intensity, but negatively correlated with the initial ACE concentration. Complete degradation of 10–20 mg/L ACE was observed within 30 minutes of solar light irradiation at an intensity of 100 mW/cm<sup>2</sup> and a pH of 6 (Subedi & Kannan, 2014).

#### Fenton process:

Another often used technique for handling persistent organic pollutants is the Fenton procedure. The elimination of AS has been studied using the electro-Fenton technique. The electro-Fenton method, which uses carbon felt cathodes and Pt or boron-doped diamond anodes, was reviewed (Ma et al., 2017a), proved effective in removing SAC from water. According to pseudo-first-order kinetics, the electrochemically produced hydroxyl radicals may totally destroy SAC in about half an hour (table 3). The primary by-products identified were inorganic ions like NH<sub>4</sub><sup>+</sup>, NO<sub>3</sub><sup>-</sup>, and SO<sub>4</sub><sup>2-</sup>, which were produced from the heteroatoms in SAC, and aliphatic chemicals like maleic, formic, and oxalic acids (Schleheck & Cook, 2003).

**Table 3:-** Different artificial sweeteners with their permissible limits as per body weight.

Artificial Sweetener	Permissible limit (mg/kg of body weight)	Reference
Aspartame	50	[1]
Saccharin	15	[2]
Sucralose	5	[4], [5]
Acesulfame potassium	15	[6], [12]
Cyclamate (in some countries)	11	[10], [18]
Neotame	2	[2]

#### Plant uptake of artificial sweeteners:

According to a recent study, the mixotrophic plant *Lemna minor* has the ability to absorb and digest large amounts of SUC, a sugar replacement, increasing its capacity for photosynthetic activity and green leaf area at environmental concentrations of 0–150,000 nmol/L sucralose (Amy-Sagers et al., 2017). A research indicated that plants in heavily polluted soils absorbed ASs considerably. Vegetables grown near pig farms showed the presence of ASs, with concentrations ranging from 51.0 - 108 µg/kg dry weight for ACE, 81.6 to 181 µg/kg dry weight for SAC, and 56.7 to 275 µg/kg dry weight for CYC (Ma et al., 2017b). These results provide important information about the potential use of appropriate plants for bioremediation in ASs-contaminated areas, even though the uptake of ASs by plants is influenced by a number of factors, such as differences in plant physiology (such as vascular versus non-vascular), the duration of toxicity experiments, and the chosen metrics, such as ecological structure, function, behaviour, or mortality (Amy-Sagers et al., 2017).

#### Waste water treatment plant:

The main purpose of WWTPs is to serve as vital barriers that stop pollutants from entering the environment. Based on their respective functions, these plants usually use a variety of processes that can be divided into three categories: primary (involving grit removal, sedimentation, etc.), secondary (using biological processes like oxidation ditches, sequencing batch reactors (SBRs), and A2/O processes), and tertiary (involving chlorination, ozonation, UV treatment, etc.). Notably, main and secondary treatments for SAC and CYC surpass 90% in removal rates, demonstrating their effective eradication from wastewater (N. H. Tran et al., 2015). The removal of these ASs was predominantly attributed to biodegradation in biological wastewater treatment processes, with sorption playing a minor role due to the high-water solubility of these compounds (table 4). In WWTP, the removal efficiency of ASP varied between 68.2% and 100% (Subedi & Kannan, 2014). In the human body, unlike other AS, ASP is nearly completely metabolized (Pane et al., 2015).

**Table 4:-** Comparison of available AS remediation strategies.

Strategies	Targeted ASs	Test conditions	Removal efficiency	Reference
UV	ACE	UV for 5 h	35%	[31]
	ACE	UV for 5 min	17%	



H <sub>2</sub> O <sub>2</sub> /UV	SUC SUC, ACE, CYC, SAC	SUC:H <sub>2</sub> O <sub>2</sub> = 1:96 34 mg/L H <sub>2</sub> O <sub>2</sub>	88.6%	[35]
Fe (II) + H <sub>2</sub> O <sub>2</sub> /UV	SUC	34 mg/L H <sub>2</sub> O <sub>2</sub> with S <sub>2</sub> O <sub>8</sub> <sup>2-</sup>	98.7%	[34]
Fenton	SUC	SUC:H <sub>2</sub> O <sub>2</sub> = 1:96	46.6%	[30]
Electro-Fenton	SUC	Anode: Pt or BDD, cathode: carbon felt	100%	[37]

### Conclusion:-

Bioremediation, as a sustainable and eco-friendly approach, has shown promise in addressing the environmental presence of AS. The extensive use of ASs in various products, coupled with their resistance to conventional wastewater treatment processes, has led to their widespread occurrence in aquatic environments. In recent years, researchers have explored the potential of microbial communities to mitigate the impact of ASs on ecosystems. Various strategies have been suggested for the reduction of ASs in the environment. However, In WWTPs, the successful elimination of the chronic SUC and ACE continues to be a major concern. Tertiary treatments, such as RO, sophisticated oxidation techniques, and ozone with GAC, may provide desired performances for the removal of SUC and ACE. Nevertheless, these approaches are rendered impractical for broad implementation in WWTPs due to their high costs and intricate procedures. Potential substitutes are biologically active filters, including artificial wetlands and slow sand filters.

It is crucial to remember that the several AS that are utilised worldwide might differ in terms of their prevalence, concentration, and ecotoxicity in various ecosystems. Because AS is becoming more common and in greater numbers along with other environmental conditions and contaminants, findings recorded a few years ago may not accurately reflect the current situation. The necessity for thorough risk assessment, estimate, ecotoxicity testing, and the removal of these new pollutants is highlighted by the mounting evidence of higher concentrations and ecotoxicity of ASs in the environment. The review emphasizes the ecological impact of AS and their breakdown products, recently classified as emerging contaminants. The presence of ASs and their degradation products in aquatic systems poses a new threat to aquatic life due to their significant concentrations. Beyond addressing testing methodologies, estimation techniques, sources, and transformation pathways, the review is expected to provide valuable insights for the scientific community regarding future prospects in environmental safety assessment.

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### Conflict of interests

The authors declare no conflict of interest with anyone.

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