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The Imminent Electrochemical Activation Aspects, Recent Advancements, And Few Application-Specific Evidence In Different Sectors (A Review)

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Abstract

The science behind electro-activation is known as managed and balanced electrolysis, and it works by exposing an aqueous solution to the actions of an exterior electrical field in an electrochemical reactor. The primary feature of electrochemically activated aqueous solutions (ECAAS) is that whenever they are confined to unipolar electrochemical influencing factors with specific properties, a metastable state occurs, i.e., electrochemically activated compounds, providing them with distinctive ecological, physiological, chemical, biological, and specifically microbiological features that none of the presently accredited chemicals like pharmaceutical industries, biocides, and cosmetic products have.The catholyte has elevated electron activity and reducing qualities, whereas the anolyte has decreased electron activity and noticeable oxidant qualities. The anolytes' low oxidant concentration results in relatively minimal chemical buffering, which contributes to ecological sustainability. The wide-spectrum antibacterial action of electrochemical activation solutions has been demonstrated, and given their inexpensive raw material costs and simple synthesis (in-situ or remotely), they hold great promise for widespread use in many sectors including healthcare. The benefits of the ECAAS have given rise to its widespread use in a variety of fields, including those related to human beings and veterinary medicine, the food sector,defence, wagons, ships, aircraft disinfection, etc.The emphasis of this review is on the many applications and most current developments of electro-activated solutions across different industries.

Keywords: Electro-activation, Anolyte, Catholyte, Oxidation-reduction potential, Antibacterial activity, Multidrug-resistant

I. INTRODUCTION

The science of electro-activation is the study of the activation energy, thermodynamics, and physical and chemical characteristics of aqueous solutions subjected to the operation of an electric field through specificsituations in which the huge distribution of anions and cations is influenced by the special arrangement of ion exchange membranes.Catholyte and anolyte solutions obtained throughout electro-activation have distinct features. As a result of the electro-activation process, the solutions are usually in metastable form with substantially altered properties in terms of oxidation-reduction potential (ORP), the total number of reactive and active species, pH, as well as dissolved gases which includes hydrogen and oxygen. Electro-activation is a subfield of applied electrochemistry that investigates the response of solvent solutions after they have been excited by an electric field to adjust the activation energy needed for the chemical reactions that occur there. Electro-activation of aqueous systems is an electrolysis technology of water that has been examined for over a century and depends upon Faraday's electrochemistry works. Additional research has been carried out on this technology, primarily in the ex-Soviet Union (USSR), to know well about the nonconventional modifications of aqueous medium (which includes water) and their potential applications in various areas. The electrolysis reactions reinforce the unipolar electrochemical activation of solvents. The end outcome of electrolysis of concentrated solutions is a sheer readily available product, whereas electrochemically activated are weak (up to 5 g/l) aqueous salt solutions or drinkable water, which consists of up to 1 g/l of various salts.

The eminent electrolysis reactions justify the unipolar electrochemical activation ofliquids. However, the end outcome of a concentrated solution of electrolysis is perfect for use, whereas electrochemically activated are weak solutions of salts (maximum till 5g/L) or drinking water, which consists of various salts (maximum till 1g/L). Electrochemical activation is utilized to transform a solvent into an excited form. ECA was discovered to be able to transform fresh water with low salt into an extremely effective technical solution with multiple operational properties while requiring no extra investment.

Before becoming prominent in several other advanced nations including the United States, Canada, and China, EA technology was acknowledged in Japan as a useful investigation [1, 2]. In practice, electro-activation is depicted as a potentially exciting technological innovation for food security and the manufacturing of foods which is processed by low heat. It is of great importance because of the latest trend in ecological and environment-friendly innovations [3]. When they are employed for unipolar electrolytic effects with particular qualities, they form metastable states, i.e., electrochemically stimulated compounds, with special ecological, biological, and specifically physicochemical qualities that currently licensed compounds like biocides, pharmaceuticals, and cosmetics lack. Sodium chloride electrochemically activated aqueous solution (ECAAS) considered a wide-ranging, ecologically friendly biocidal component in past decades. Their scope of action extends beyond bacteria which includes fungi, viruses, and spores. Even though bacteria are present in biofilm form, they are effectively hindered. There is scientific proof that the antimicrobial action of these solutions is greater in comparison to alcohol and comparable to that of the sodium base effect. They can be utilized to disinfect floors, tools, worktops, surfaces, packs, hands, and much more, and their efficacious action has no negative side effects [4].

Salts of citrate, acetate, and lactate have demonstrated antibacterial efficacy towards foodborne pathogens such as *Staphylococcus aureus* and *Yersinia enterocolitica* as well as an inhibitory impact on the proliferation of various food-spoiling bacteria[5], *Listeria monocytogenes*[6], *Escherichia coli*[5, 7] as well as *Clostridium botulinum*[8]. Additionally, several organic acid salts have been observed to have a modest antibacterial effect when used to treat meat that is deteriorated due to lactic acid bacteria [9, 10]. The ability of potassium salts to hinder microbe growth has also been investigated. On harmful bacteria, such as *L.monocytogenes, Vibrio parahaemolyticus,*and *Clostridium perfringens*, several studies have documented suppressing effects[8].

APPLICATIONS OF ELECTROCHEMICALLY ACTIVATED SOLUTIONS IN HEALTHCARE SETTINGS

Biocides are an effective pre-emptive control for the expansion of multiple drug-resistant bacteria and nosocomial infections in various healthcare systems. Many biocides, when used often, cause significant respiratory and dermatological ailments in both patients and healthcare employees.When used excessively, biocides such as glutaraldehyde degradation of equipment and impair endoscopes [11]. To address these healthcare issues, it is necessary to look for new options. Over a century has passed since the first-time electrolysis was utilized to disinfect [12].

Wound infection management and prevention

Targeted antimicrobial therapy is crucial for the treatment of recognized wound infections such as *Staphylococcus aurues* however, the widespread use of broad-spectrum antibiotics is being curtailed due to the increase in antimicrobial resistance. It has been demonstrated that using an acidic ECASa (electrochemically activated solution) twice a day to wash infected lesions or ulcers will lower bacterial infections and facilitate debridement [13]. A *P. aeruginosa*-infected rodent in vivo burn wound model underwent ECASa therapy, which also resulted in a decrease in blood endotoxin levels and a substantial improvement in mortality rates [14]. ECASa is believed to aid in the promotion of recovery by minimizing the bacterial load, improving local blood flow, speeding neovascularization, decreasing inflammation, and creating an antagonistic environment for opportunistic pathogens[15].

Curing and preclusion of periodontal disease

ECASa can eliminate the smear layer from root canals in vivo, according to preliminary research[16],and was equally efficient as chlorhexidine at preventing plaque development in human volunteers [17]. An ESEM-based pilot investigation on detached teeth revealed that the administration of ECASa and ECASc together might be employed as an efficient root canal cleaning solution in comparison with sodium hypochlorite [18].

Decontamination of the environment

Various pathogenic microbes can thrive on the broad range of surfaces and equipment present in the hospital setting and continue to be a concern in addition to being directly transmitted between patients. While viruses may only live for a short duration, bacteria may either use the reduced nutritional sources to thrive for months [19] or can go quiescent (for example, spores) until they’re subjected to an environment that will allow them to proliferate. MRSA, norovirus, and *Acinetobacter baumannii* are all susceptible to the action of fogged ECASa [20, 21]. This may be beneficial for disinfecting huge areas (like medical wards), and utilizing fogged or aerosolized ECASa strategically could prevent outbursts of infections linked to healthcare.

UTILIZATION OFELECTROCHEMICALLY ACTIVATED AQUEOUS SOLUTIONS IN THE PRODUCTION OF FUR PRODUCTS

The impact of EC water on the chemical and physical attributes of the reagents is of significant relevance since it is used throughout the preliminary phases of manufacturing leathers and furs. These reagents include sodium bicarbonate, sodium carbonate, and sodium sulphate. According to research by [22],the watering of fur skins in an anolyte's electro-activated solution may comprise an interaction between hydrogen protons and the carboxyl groups of collagens which is negatively charged, and in catholyte, between the carboxyl groups and amines of collagen.H^+ and OH^- ions are synthesized by diluted acids and alkalis in current leading technologies.Ionic bonds between amines and carboxyl groups of polypeptide chain R-radicals are disrupted when electro-activated water of anolyte is employed, allowing biopolymer's amines (when anolyte is used) to preserve their positive electrical charge, however, ionized carboxyl groups are released. Due to an ion-dipole link and coulomb repulsion, this causes the collagen in the skin tissue to become more hydrated, which in turn causes fur skins to become more water-soaked.When using catholyte instead of anolyte to wet fur skins, the neutralization of ionized collagen amines speeds up the soaking procedure.Thus, it was determined that the development of skin tissue with hydro-thermal resistance is in line with the active standard and may be achieved effectively by using processing mediums depending on electro-activated water and less chemical reactant than the technology currently used to manufacture fur.

ETHIONAMIDE ELECTROCHEMICAL ACTIVATION BASED ON GRAPHENE OXIDE FOR IMPROVED BIOLOGICAL ACTIVITY

A second-line anti-tubercular medication for the treatment of TB is ethionamide (ETO) or 2-ethyl thiosonicotinamide. It has been widely utilized to treat multi-drug resistant tuberculosis since it is an analog of ionizing and bacteriostatic in terms of structure [23]. Since ETO is metabolized primarily in the liver, only 5-7% of the medicine is eliminated unaltered in the urine, leaving a comparably high quantity of the antibiotic in the body that causes negative impacts [24]. Graphene oxide (GO), an existent carbon allotropic compound, is superior to graphite as an electrocatalyst because it has a larger surface area, reduced weight, and higher tensile strength. GO is one of the most effective nanostructures for enabling high mobility for electron transport [25]. Additionally, because graphene-based electrocatalysts can react with various compounds in reaction media and are structurally and morphologically immovable, they operate as homogenous polymer compounds that might be recycled andreused.Due to all of these characteristics, GO is anexcellent electrocatalyst for improved conversion efficacy at reduced overpotentials [26, 27].

In [28]work, a considerable rise in the current density of anolyte on GO indicated that electron transport in GO is much more practicable than in bare GC for the ETO oxidation process. Due to the constant numbers of edge planes, there was no discernible difference in the electrochemical outputs of single and multi-layer graphene specimens, indicating that the electrocatalytic activity of graphene was inversely proportional to the graphene sheets. However, since graphene possesses more edge planes per unit mass than solid carbon, there was a noticeable variation in the activity between both electrodes. The outcome was an inclination in current density and a reduction in overpotentials, which impacted electrocatalytic performance [29].

THE RECOGNITION OF ANTIBIOTIC RESISTANCE USING ELECTROCHEMICAL TECHNIQUES

A serious menace to public health worldwide is now posed by the quick emergence of antibiotic resistance in both cancer and microorganisms like bacteria [30]. Protein mutations in cell membranes, changes in intracellular drug targets, and the proliferation of efflux pumps are examples of resistance mechanisms of cells that are present in bacteria and cancer [31 – 33]. The latter occurs as an effect of efflux pump proteins being overexpressed, which allows cells to quickly evacuate antibiotics from the cell interior before these substances can exert their intended effects [32]. The electrochemical community has increasingly focused on innovating novel approaches to comprehend and identify resistance to antibiotics in bacteria and cancer using electrochemistry. These approaches use drug compounds and active efflux pump proteins.

It is essential to determine relevant target analytes and comprehend how they interface with biological cells to recognize antibiotic resistance by electrochemistry. Electrochemical sensors are a breakthrough that has drawn a significant amount of interest because of their quick analysis, great sensitivity, and capabilities to assess complicated specimens like urine and blood. Electrochemical sensors can efficiently and precisely detect an analyte and are sensitive and affordable. Due to these characteristics, electrochemistry is considered an appealing technology in clinical applications [34].Drug compounds' redox characteristics must be thoroughly understood to explore antibiotic resistance electrochemically. Inhibitors, antimetabolites, cytotoxic antibiotics, and alkylating agents are the four categories into which anti-cancer medications that have been electrochemically described in the previous ten years are divided. While DNA-binding alkylating agents like cisplatin cause cells to die in case of cancer, antimetabolites like 5-fluorouracil and 6-mercaptopurine imitate metabolites to obstruct mechanisms necessary for cell proliferation [35, 36].[37] suggested electrochemical techniques to assess curcumin's impact on the highly malignant tumor i.e. glioblastoma cells U87MG (Fig. 1). The findings revealed that when curcumin content rose, cell viability decreased. The suggested electrochemical approach, according to the authors, is superior to conventional colorimetric techniques in terms of sensitivity, accuracy, and the absence of optical intrusions.

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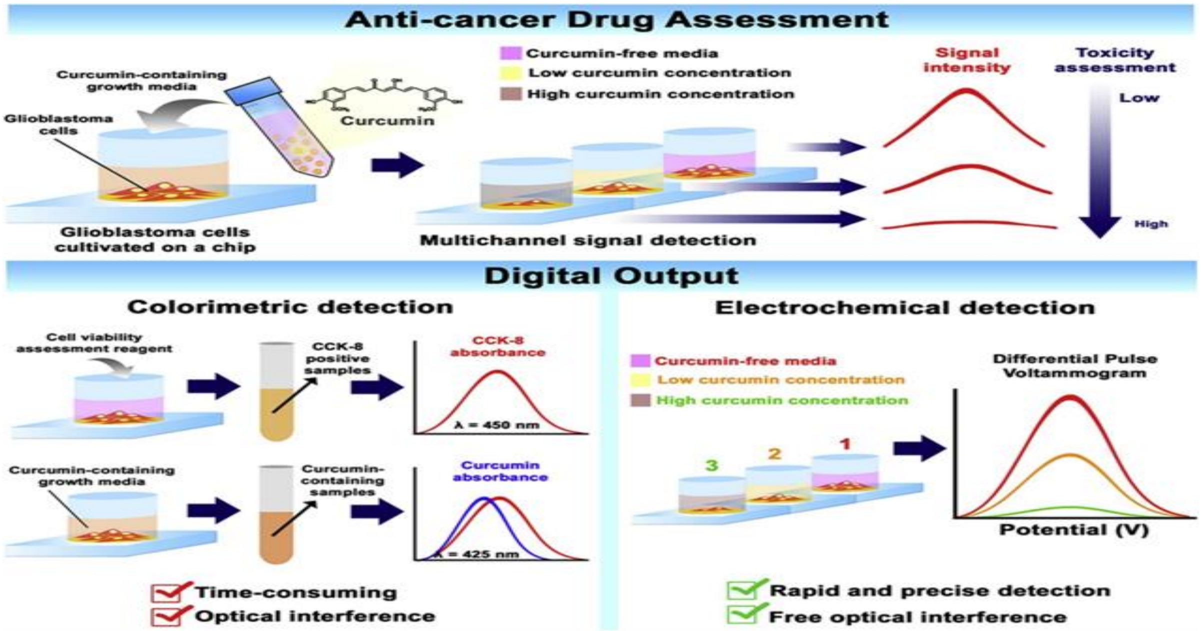

Fig. 1. [37] suggested an electrochemical method for determining curcumin's anti-cancer properties using human glioblastoma cells as shown schematically in the figure.

ELECTRO-ACTIVATED WEAK ACIDS SOLUTIONS' ANTIBACTERIAL ACTIVITY

Food-grade organic acids (citric acids and lactic acid) are frequently employed as natural biocides to stop the emergence of infections in a diverse range of foods [38]. They are reasonably priced and ecologically friendly. However, because of their potential to harm, as well as the risk of worker intoxication or injury, concentrated organic acids used in industry must be handled carefully and stored under particular circumstances [39, 40].Inresearch conducted by EI Jaam and colleagues, the mixed-use of electro-activated potassium citrate and potassium acetate at temperatures of 95, 105, and 115 °C in vegetable puree showed excellent effectiveness against *Clostridium sporogenes* spores, with a low effect of ≥ 7 log CFU/ml [41]. According to research by [42], a considerable suppression of the development of *Staphylococcus aureus, Salmonella enterica,* and *Listeria monocytogenes*was shown when the antimicrobial properties of organic acids solutions and electro-activated solutions were assessed.Therefore, it was revealed that all isolates were suppressed or significantly harmed with a drop of≥6 log CFU/ml following 10 min of exposure to electro-activated potassium acetate solution. Hence, it was demonstrated that *Staphylococcus aureus, Listeria monocytogenes, and Salmonella enteric* seem to be more susceptible to an electro-activated solution of calcium lactate, and potassium acetate in comparison to potassium citrate (Fig. 2. And Fig. 3)

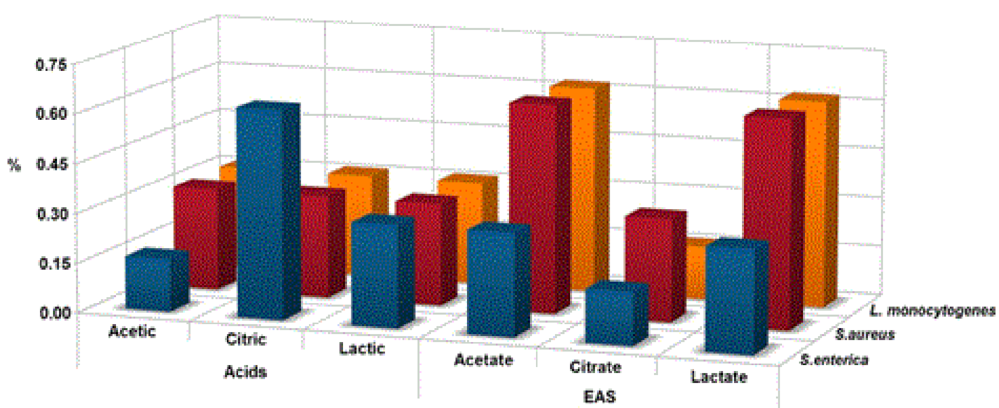

Fig. 2.Utilizing electro-activated organic salt solutions and their organic acids, to determine the minimum inhibitory concentration (MIC) for the bacterium[42].

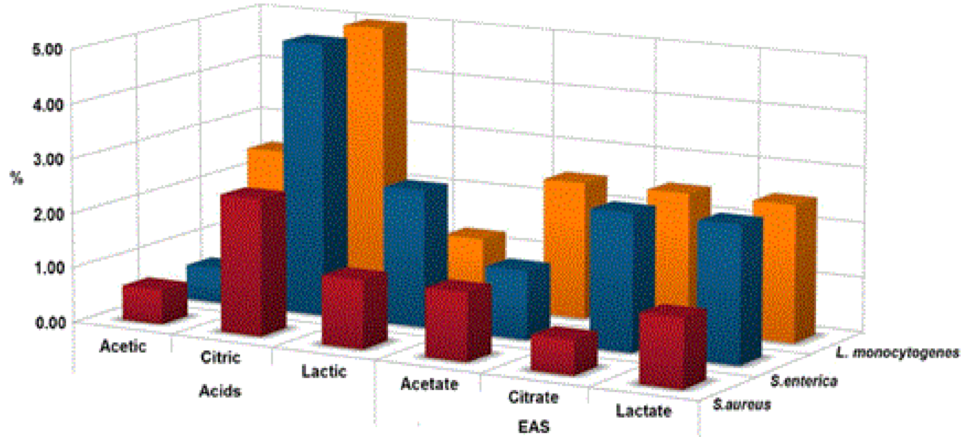

Fig. 3. Determination of the minimal bactericidal concentration (MBC) of the electro-activated solutions of weak organic acids salts and the commercially accessible organic acids on the studied bacterial pathogens[42].

VETERINARIAN APPLICATIONS OF ELECTROCHEMICALLY STIMULATED SOLUTIONS

The electrochemical activation of aqueous saline solutions is a liberal and effectual technology, according to the practical exposure of a variety of cattle breeding farms. It enables a substantial decrease in material, energy, and labour costs for the generation of impactful washing, disinfectants, and other bioactive plans. Precise and constant adherence to the procedural guidelines and technical norms of their synthesis in the available equipment is necessary for the effective use of ECA solutions at veterinary regulatory facilities. The utilization of electrochemically activated chloride solutions as antiseptics on the skin, cavities, mucous membranes, and lacerations to diagnose and treat local infections, in situations of burn injuries, for countering foot rot, and to be introduced into the body's internal surroundings for reducing and managing gastrointestinal, lung illness, specificallyof agricultural young stock animals, has acquired a significant amount of expertise in both healthcare and veterinary actions.[43] discovered that an anolyte made by electrochemically activating an aqueous solution of sodium chloride and sodium carbonate had a clearly stated antibacterial effect after being exposed to lagoons used to store cattle excrement for 48 hours.

It is essential to keep in mind when utilizing ECA solutions that anolytes exhibit their highest cytotoxic activity within the first 24 to 48 hours of production (during relaxation). It is also advised to only use newly made ECA solutions, as the existence of naturally occurring and other pollutants on the substrate's surface reduces the anolyte's potential to disinfect. However, surfaces pre-treated with catholyte solution, on the other hand,eradicate the aforementioned limitations. According to the research of [44], the 12 mares chosen for the experiment had their reproductive potential assessed. Four to twelve hours following insemination, transrectal ultrasonographywas used to further evaluate mares in the treated group, and the detection of intraluminal uterine fluid was identified. A 100 ml intrauterine administration of electrochemically activated saline at room temperature was then given to the treating groups of mares. The mixture was created below 24 hours ago and placed straight within the uterus.Based on the observations, the per-cycle conception rates of pony mares were not negatively affected by the post-breeding intravenous infusion of electrochemically activated saline.

II. CONCLUSION

This study illustrates that the need for concentrated acids in the food business may be eliminated by employing electro-activated solutions of salts of weak organic acids as more effective preservation compounds. Electro-activation research enables the development of healthy, nutrient-dense, low-heat processed foods. Globally, we anticipate that their high reactivity will make them highly potent antimicrobial agents, which will help to reduce the usage of numerous chemicals in food manufacturing and storage. Additionally, because pH and acidity have a significant influence on preserving food, texture, and flavourthe electro-activation technique may assist industrial producers in effectively managing these variables and creating meals with superior quality and prolonged shelf lives. Further investigation is essential to fully understand how these EAS (Electro-activated solutions) affect virulent and spoilage microbes.

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V. CONFLICT OF INTEREST

The authors affirm that there is no conflict of interest among them.

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