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Electrospinning of biopolymers and synthetic polymers and their applications in the food industry

Madhiraju Rajithasri and Pasala Rajkumar

Abstract
Electrospinning is a simple and efficient technology that utilizes high electrostatic potentials to draw polymer solutions or polymer melt into fibres or particles. The structure and the physicochemical properties of electrospinning fibres can be tailored according to the end application, and for this reason, electrospinning is a versatile and appealing technique. Several potential applications in which electrospinning may provide a plausible solution have been reported mainly for the bio and food-producing or developing fields. This area is highlighted by some recent advances carried out by electrospinning in food packaging, and sensing applications.

Keywords: Electrospinning and its types, physicochemical, plausible solution

Introduction
The electrospinning technique was first developed in the early 1900s. It is voltage- a driven process by the electrodynamics phenomena in which fibres and also particles are made from a solution of polymers (Bee, 2019). The diameter of the fibers typically ranges between nanometres to a few members of a micrometer. The main advantage of the electrospinning technique is the versatility of processing to create fibers with multiple arrangements and morphological structures. The popularity of the electrospinning technique has allowed multiple technological processes such as tissue engineering, regenerative medicine, and encapsulation of bioactive molecules in food industries (Mark, 2021).

Electrospinning is simple and effective for producing submicrometric or nanoscale polymer fibers. A typical electrospinning system consists of a high-voltage power supply, syringe pump with a metal needle, and grounded collector, either a plate or a rotating drum. In electrospinning, a polymer solution or melted polymer is extruded out to form a droplet at the needle tip by a syringe pump (Andriyana, 2019). During this process, an electric field is applied between the needle tip and the grounded collector and the surface of a droplet into a conical shape through the action of electrostatic forces. When the electrical force overcomes the critical surface tension of the polymer liquid, an electrically charged jet of the polymer is ejected from the tip of the Taylor cone, stretched, and finally deposited on the collector as fibers ranging from micrometers to nanometres in diameter (Amalina, 2019).

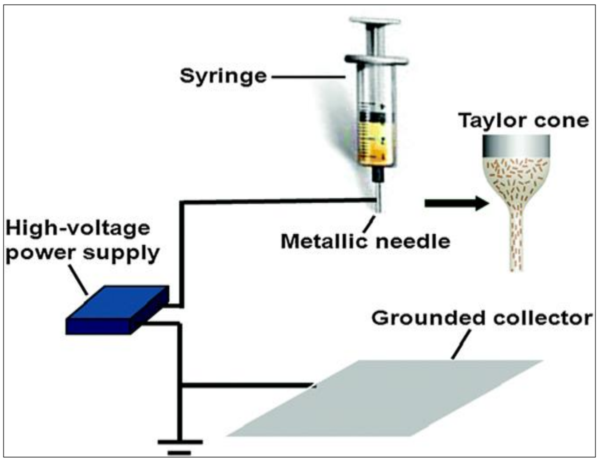


Fig 1: Electrospinning technique (Shariful, 2019)

Nowadays the electrospinning technique is not only for academic research work, but it is one that is helping in many real commercial applications. Presently, multiple industries around the world have adopted this technique in the development of new product innovations and other techniques. Some of the applications where electrospinning is being currently used are food encapsulation, tissue engineering, drug delivery, insulating materials, energy conversion and storage, air and water filtration, and many more (Sebatian, 2021). The bio-active compounds are the active agents in food packaging materials and nutraceuticals in functional foods play a major role. The main application of bioactive compounds is often restricted by their unfavorable flavor, solubility, their poor stability during food processing, which can significantly compromise their biological benefits (Francisco, 2021).

Various Types of Electrospinning

There are two types of electrospinning systems.

Needle based electrospinning

When the initial polymer solution is contained in an air-tight closed reservoir during needle-based electrospinning, solvent evaporation is minimized and prevented. This important difference allows a wide variety of materials, including high volatile solvents, to be easily processed. There are many advantages of needle-based electrospinning, including flexibility to the process of different structures like core-shell and multi-axial fibers. When the initial polymer solution is contained in an air-tight closed reservoir during needle-based electrospinning, solvent evaporation is minimised and prevented (Lu, 2014).

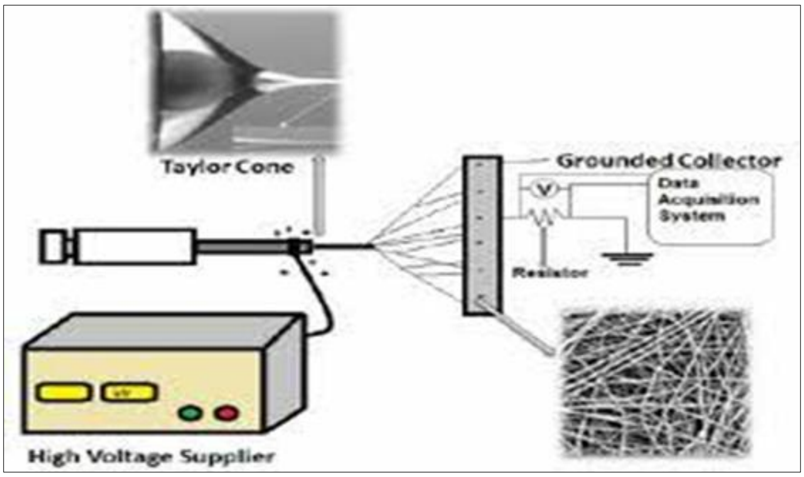


Fig 2: Needle based electrospinning (Lu, 2014)

1. Multi- axial (or) Coaxial Electrospinning: Multi-axial (or) coaxial electrospinning is a spinneret that is composed of an outer and inner needle. This electrospinning can generate the fibers from the various solutions, core-sheath, hollow and functional fibers which may contain particles. This method of electrospinning is used to create hollow fibers, with a temporary substance serving as the actual material. Depending on the process, oil is used as a temporary material because it is easier to remove them than other higher molecular weight materials. Under the high voltage, the liquid is drawn out from the spinneret and forms a compound Taylor cone. Following the coaxial jet, the core-shell structure is generated and maintained in the fibers by spinning solid, which is then collected on the collector (Khalf, 2016).

Multi electrospinning has been used to resolve the premature solidification process that may occur at the tip of the nozzle during the process, mainly when high volatile solvents are used. The volatile solution was fed into the inner nozzle while the nitrogen gas was fed into the outer nozzle. The same solvent with the core solvent was selected to generate the vapor for the outer nozzle. With the effective gas jacket which is present, the Taylor cone solidification is reduced. In this case, a very stable Taylor cone and liquid jet ejection were maintained, while the solution at the nozzle without the gas jacket experienced solidification or clogging issues. In this case, increasing the gas flow rate can change the fiber morphology from fibers to microparticles without changing solution properties (ma, 2016).

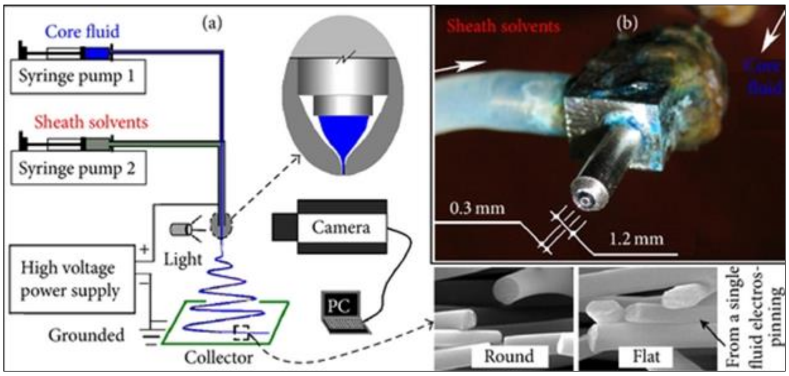


Fig 3: Multi axial or co-axial electrospinning (Khalf, 2016)

2. Tri-axial Electrospinning
The volatile solution was fed into the inner nozzle while the nitrogen gas was fed into the outer nozzle. The Charged liquid at the nozzle orifice is drawn out by an electric field to form a jet. Selected polymers could be loaded with nanoparticles using the tri-axial electrospinning process. These particles have a beneficial use for controlling and enhancing cell proliferation and migration (Steckl, 2016). Tri-axial fiber could also be used to deliver two different drugs with the dual delivery system by using the intermediate layer that acts as an isolation layer between the shell and core materials. The tri-axial fibers can be formed with different features such as hydrophobicity and mechanical strength. Formation of the fiber and outer sheath is extracted and the inner sheath allows fibers of polymers and those polymers cannot be electrospun on their own (Han, 2016).
Tri-axial electrospinning fibers with self-healing capability are fabricated through a direct, tri-axial electrospinning process. They have been designed to have two distinct protective walls to encapsulate resin and its hardener as healing agents in separate cores. The presence of an extra layer between encapsulated liquid healing agent and an outer layer that enables the encapsulation of chemically and physically active healing agents extends the efficiency and functionality (Zanjani, 2017).

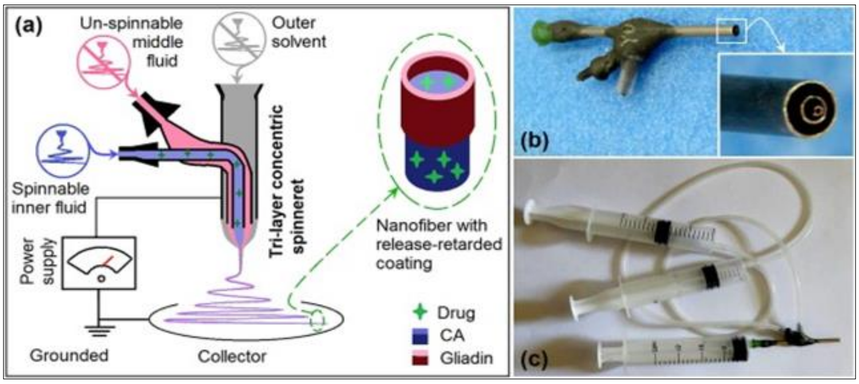


Fig 4: Tri-axial electrospinning (Gareth, 2019)

3. Bi-Component Electrospinning
In Bi-component electrospinning, where the two plastic syringes each containing a polymer solution lie side-by-side. A common syringe pump controls the flow rate of the two polymer solutions. The platinum electrodes dipped in the solutions are connected parallel to the high voltage DC supply. The Teflon needles attached to the syringes have their free ends taped together. An advantage of the side-by-side bi-component fiber is that the single fiber is able to express the characteristics of each of the components of the fiber (Pankaj, 2017).

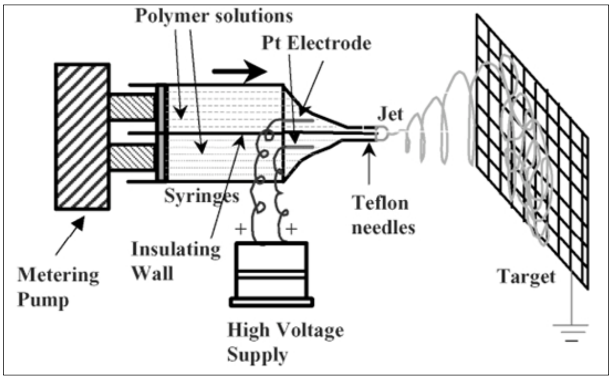


Fig 5: Bi-Component electrospinning (Pankaj, 2017).

4. Multi-needle Electrospinning
Multi-needle electrospinning is a method for mass production of nanofibers, which can improve the production efficiency of nanofibers by increasing the number and density of needles for multi-needle electrospinning. When the arrangement density of the needle is high, the electric field of tip of the needle is not uniform, causing instability such as jet dripping and broken jet (Yuman, 2019). The electric field uniformity optimization problem of multi-needle electrospinning technology is used to simulate the needle tip electric field by using finite element analysis software. The method of using dielectric material on the tip of the middle part of the needle is beneficial to the electric field uniformity. The uniformity of the needle tip electric field in the case of the high-density arrangement of the needle is realized, and the nozzle is provided for mass production of nanofibers by multi-needle electrospinning (Slehhudin, 2017).
In Multi-needle electrospinning, the polymer solution is forced through multiple needles connected to a high voltage supply. The syringe pump is used to pump the spinning solution to the spinneret setup. Different spinning solutions can be pumped on their own to the two different sets in the same multiple spinneret setups. Due to the large amount of spinning solution delivered, a high voltage is required for continuous electrospinning (Madihally, 2016) [4].

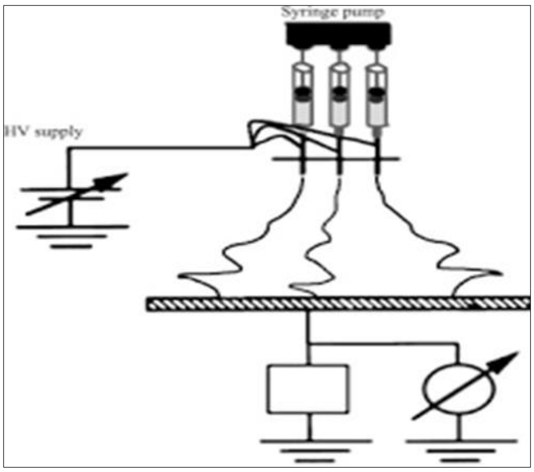


Fig 6: Multi-needle electrospinning.

5. Electro blowing /Gas-assisted Electrospinning

Electro blowing or Gas assisted electrospinning is a technique combining electrostatic nano fiber production with an airflow around the spinneret. The tangential forces of the flowing air acting on a drop of mixture contribute to the formation of the Taylor cone and to the creation of the nano fiber. With the additional stretching force provided by the gas jet, small diameter fibers have been produced. The Combination of different forces of electric field is applied and the airflow increases and it accelerates the evaporation of solvent from the solutio (Shen, 2017) n.

Electro blowing is similar to melt blowing in the process that uses a gas jet to aid in the extension of the spinning jet. The melt blowing uses only the drawing force from the gas jet to elongate the fiber while electro blowing, more on electrostatic repulsion to stretch the fiber with the gas jet facilitating solution drawing at the initial phase only. The diameter of melt-blown fibers was compared with those from melt-blown with electrospinning. For the latter fibers, the melt blowing die was connected to a high voltage power supply to introduce electrical charges as in electrospinning. Their results showed that with electrospinning incorporated into the melt blowing, the fiber diameter is consistently less than 1 µm while the melt-blown only fibers range from 1.2 µm to 2.8 µm. The reduction of fiber diameter when a high voltage was applied is more than 60 (Chen, 2016) %.

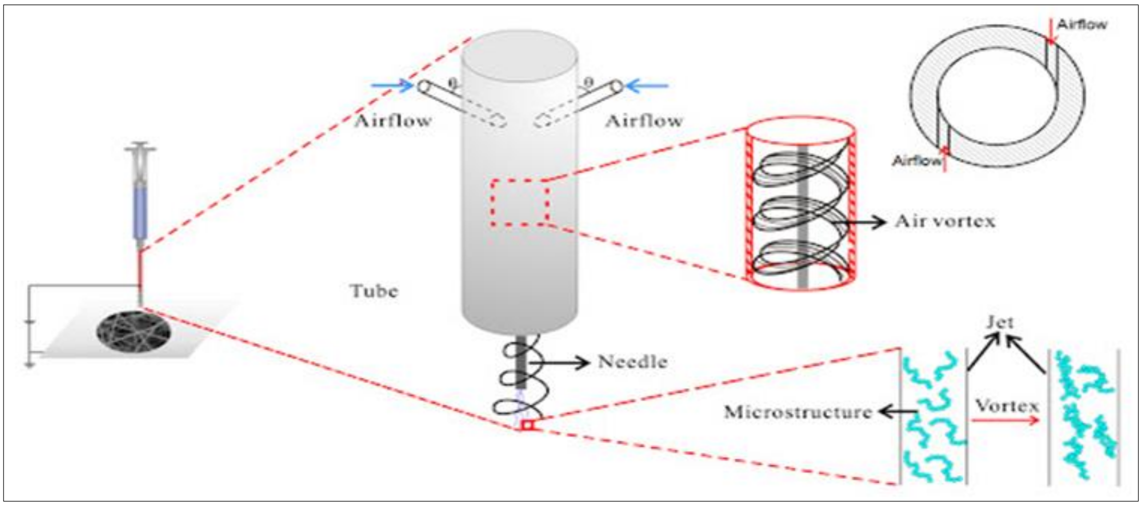


Fig 7: Electro blowing or Gas-assisted electrospinning (Tian, 2020)

6. Conjugate Electrospinning

The conjugate electrospinning consists of two or three high voltage power supplies with opposite polarity, two or three spinnerets, and a receiver drum. Spinnerets are arranged in opposite directions on the same horizontal line. The solution is separately delivered by syringes into two or three spinnerets. The receiver is a rotating drum that is controlled by a stepping motor. The fibers from the two or three oppositely charged electrospinning spinnerets are collected and stretched by the drum receiver at a constant speed. The nanofiber yarns, which can be produced by this technique, are dried under a vacuum at room temperature (Cakmak, 2018).

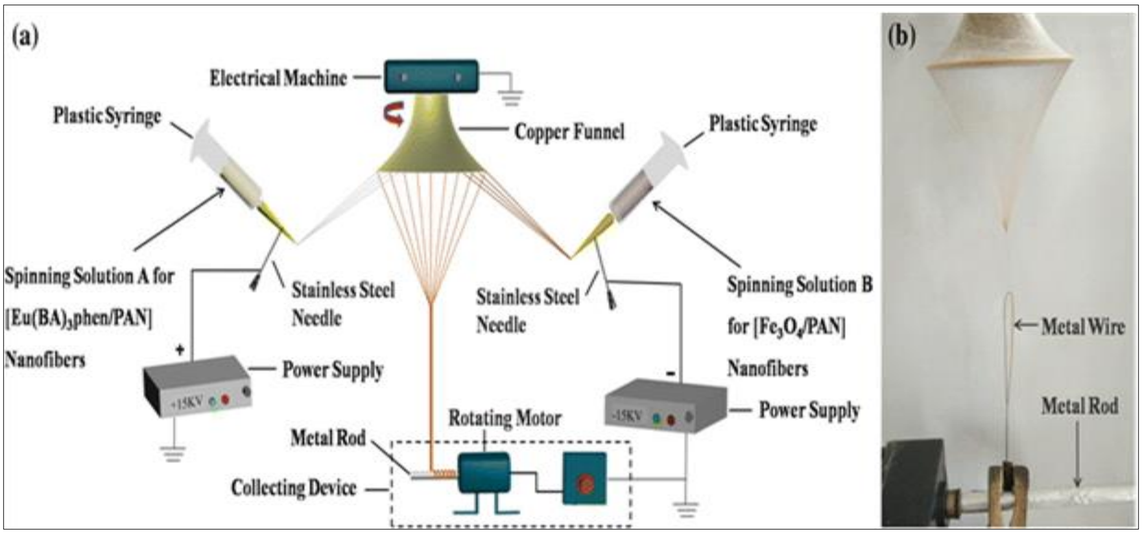


Fig 8: Conjugate electrospinning (Libing, 2018)

7. Centrifugal Electrospinning

In centrifugal electrospinning, the solution drop into fibers is a combination of centrifugal and electrostatic force. In centrifugal electrospinning, the rotation speed can be reduced by 50%. The electric field contributes to stretching the jets to very small dimensions under simultaneous evaporation of the solvent, leaving a dry nano-fibrous coating on the substrate. With the introduction of centrifugal force, a lower voltage is required to overcome the surface tension of the solution to initiate electrospinning. The combination of mechanical rotation and the reduced voltage makes an effective method for fabricating the nano-fibers. Multiple nozzles are placed around the axis of rotation to increase the production rate of centrifugal electrospinning (Emre, 2017).

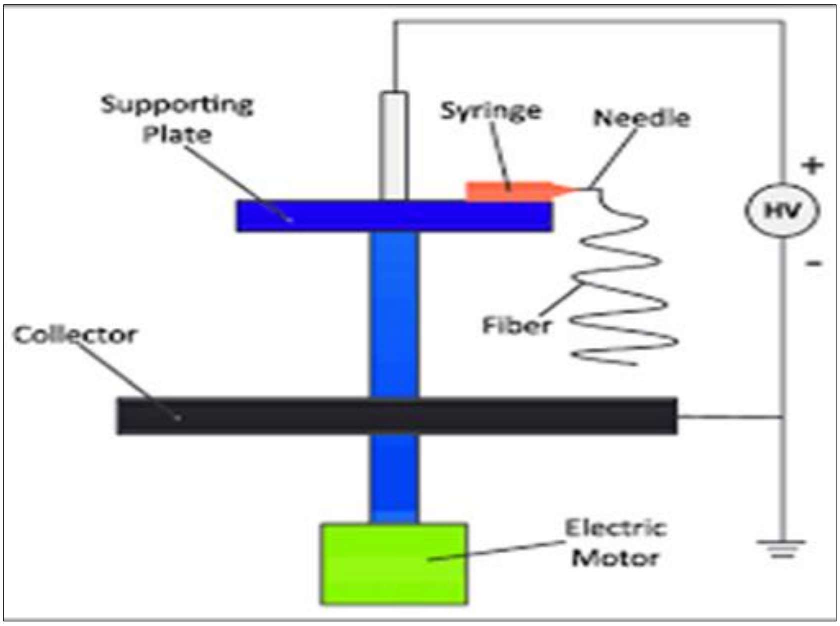


Fig 9: Centrifugal electrospinning (Zhang, 2019)

Needleless electrospinning

In needle-less electrospinning, the starting polymer solution is transferred to an open vessel where the fibers are generated from a stationary or rotating platform. Mass production of material is one of the benefit in the needle-less electrospinning process but there are many disadvantages. Fiber morphology and quality are not precisely controlled, the raw materials that can be utilized are limited, in which the fiber production and process parameters such as flow rate, cannot be controlled (Jirsak, 2015).

1. Bubble Electrospinning

Bubble electrospinning is a needless technique where the jets initiate from the surface of a polymer bubble instead of a cylindrical needle. The impact of the gas such as CO2 or N2 passed underneath the polymer solution bath causes the generation of bubble structure. The jet travels from the bubble surface at the polymer bath located at the bottom to the collector placed on the insulating floor where the fibers are collected. The fibers can be obtained by moving substrate which is connected to high voltage (Yang, 2017).

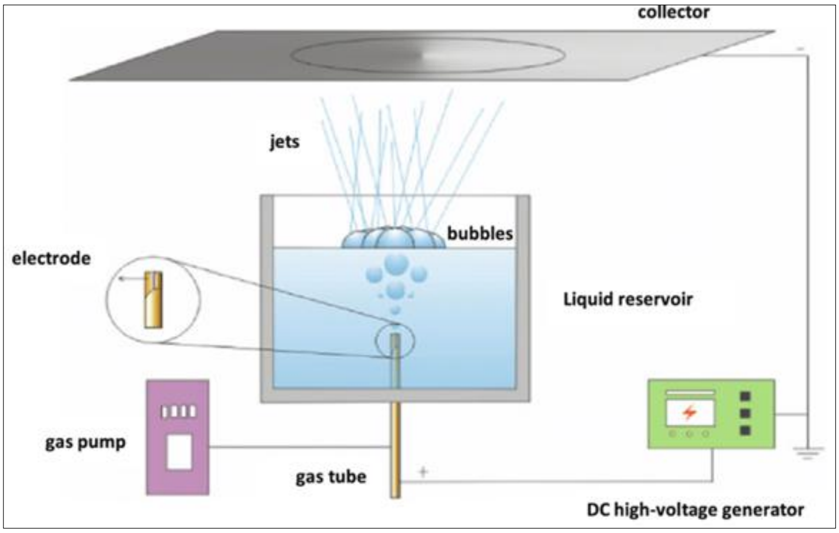


Fig 10: Bubble electrospinning (Dongyan, 2016)

2. Two-Layer Fluid Electrospinning

A two-layer system is with the lower layer being a ferromagnetic suspension and the upper layer containing polymer solution, these are subject to a normal magnetic field provided by a permanent magnet or a coil. When a normal electric field is applied in the system, the free surface becomes site of jetting directed upwards. Multiple electrified jets undergo throng stretching by the electric field and bending instability, the solvent that evaporates and solidified nanofibers deposit on the upper counter-electrode. In this type of electrospinning, the production rate is higher compared to other electrospinning (Lin, 2015).

3. Splashing Electrospinning

In splashing electrospinning, the polymer solution droplets were splashed onto the surface of a metal roller by the solution distributor, which is having a hole at the bottom. When the voltage is created, solution droplets adhering to the surface of the metal roller spinneret were ejected and stretched under the electric force to form nanofibers. This process is having the ability to perform electrospinning wan with an improved fiber production rate.

4. Melt Differential Electrospinning

The Melt differential electrospinning, in which the fibers with a diameter smaller than one micrometer can be produced at a yield of 10-20g/h using a needleless nozzle. In this process at the beginning polymer melt is distributed to the surface of the umbellate nozzles and next the melted film is covered uniformly over the circumferential surface. When the high voltage is applied then a critical value, self-organized multiple jets around the rim of the umbellate nozzle were ejected to the receiver plate. This process is given the name MD-ESP due to the melt flow dividing into tens of minor Taylor-cones. A high voltage was applied directly to the collector instead of the needle or nozzle and this allows the separation of the heating system and electrodes.

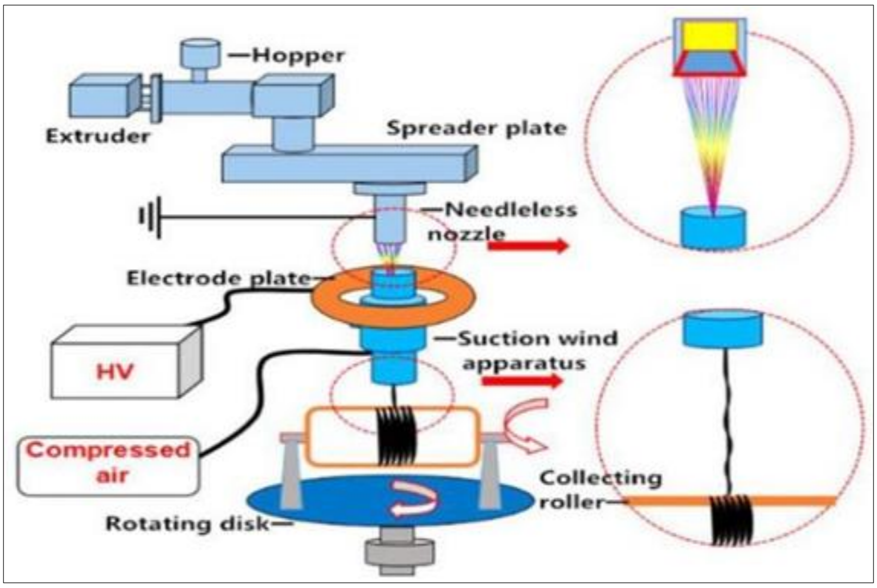


Fig 11: Melt differential electrospinning (Ma, 2017)

5. Gas Assisted Melt Differential Electrospinning

A gas-assisted melt differential electrospinning is a device with hollow disc electrode is presented. As the process of electric field force stretches the polymer melt jet into fibers, it is necessary to study that the distribution and electric field intensity of the electric field created in the spinning area is caused by the hollow disc electrode. A series of electric field simulations, including the distribution of the electric field and the relationship between electric field intensity and various parameters were carried out by the finite element method (Xei, 2015).

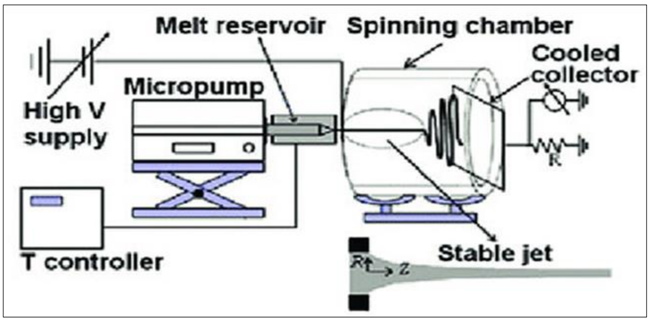


Fig 12: Gas-assisted melt differential electrospinning (Haoyi, 2018)

6. Rotary Cone Electrospinning

It consisted of four major components a high-voltage power supply, a metallic cone, a direct-current electro motor, and a collector. When using an aluminum conveyor belt as the collector, the resultant electrospun nanofiber membrane. When one drop of the PVP solution was transferred to the surface of the cone, it will be electrified with positive charges immediately. The charged liquid droplet flows along the rotating surface under the co-actions of gravity, the moment of inertia, and the electric force. Once the liquid droplet reached the lower edge of the cone, the electrospinning process started (Bingan, 2019).

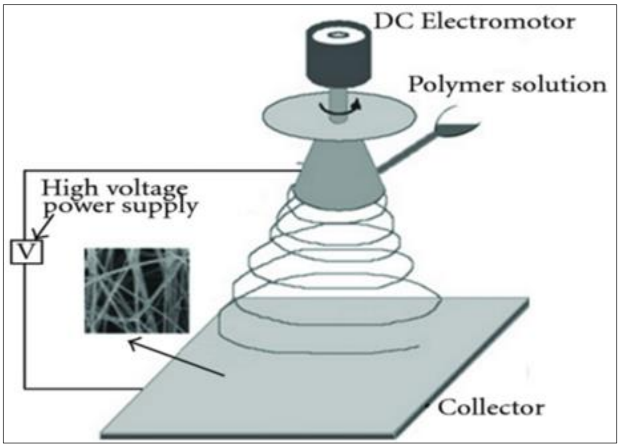


Fig 13: Rotary cone electrospinnin (Haitao, 2012) g

7. Rotating Roller Electrospinning (or) Nano-spider Electrospinning

Rotating roller electrospinning (or) Nano-spider electrospinning uses electrodes covered by the polymer solution to generate electrospinning jets. From 30 to 120 KV voltage is applied between the electrode that is submerged in the polymer solution and a collector device. The charged fibers are directed towards the oppositely charged collectors where the solvent evaporates rapidly during its traveling dry nanofiber layer is accumulated randomly on the collector device (Newehy, 2015).

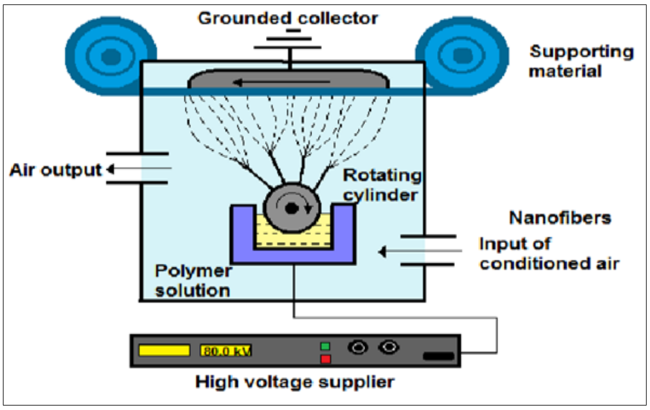


Fig 14: Rotating roller electrospinning (or) Nano-spider electrospinning (Yalcinkaya, 2011)

8. Edge Electrospinning

Edge electrospinning consisting of the fluid-filled bowl, a positive polarity high voltage power supply and a concentric, cylindrical grounded collector. Multiple jets are initiated spontaneously from the polymer fluid directly at the lip of the bowl, as well as further inside the bowl's interior which then migrate to the edge and organize to form relatively equally spaced spinning sites around the bowl circumference (Bochinski, 2011). The bowl itself serves as the source of the polymer solution instead of gravity-assisted fluid streams. An initial brief high voltage interval aids in forming the jets; subsequently, the voltage is reduced to a lower operating value for stable electrospinning and nanofiber formation. The collected fibers exhibit properties similar to those fabricated under optimal needle electrospinning conditions (Thoppey, 2011).

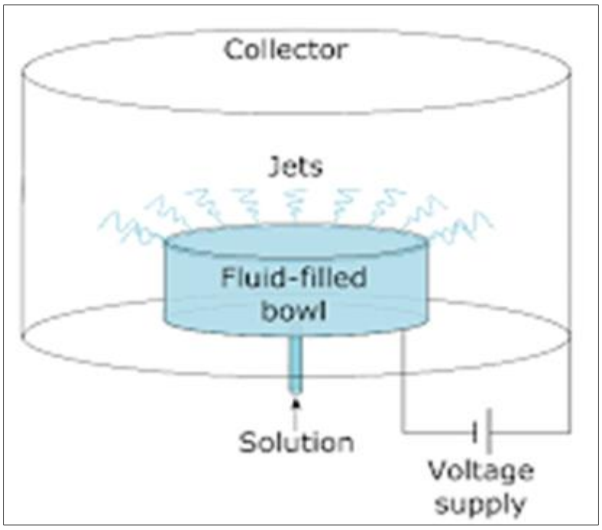


Fig 15: Edge electrospinning (Thoppey, 2014)

9. Blown Bubble Electrospinning

A polymer liquid membrane is produced by a metal ring rotating through the polymer solution, and that membrane is pulled forward by blowing air to form a bubble under the presence of a high electronic field. When the bubble is ruptured, multiple jets are ejected and accelerated by the electronic field to produce micro or nanofibers. The formed membrane on the ring is pulled forward gradually to form a hemisphere by a stream of blowing air, when an electric field is present, the blowing bubble is further deformed into a protuberance-induced upward-directed shape During this deformation, the wall thickness of the bubble reduces to about 1/2 - 1/10 of the membrane thickness. Once the electric field exceeds the critical value needed to bvercome the surface tension and multiple jets eject (RouXi, 2014).

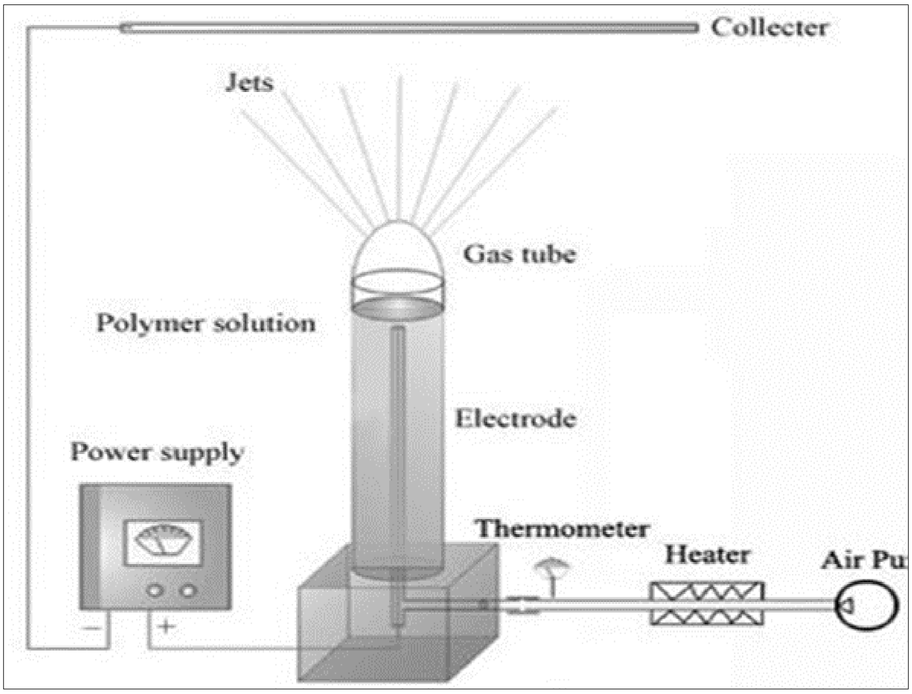


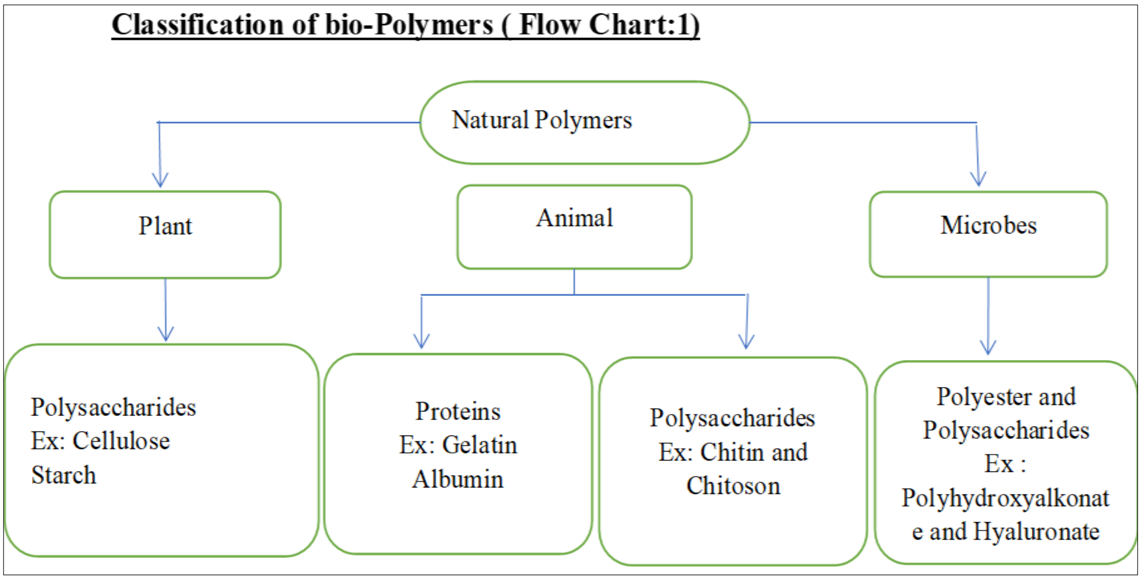
Fig 16: Blown bubble electrospinning (Haun, 2017)

Table 1: Other methods of electrospinning with their specifications

Electrospinning methods	Applications	References
Electrospinning machine with parallel electrodes	Used for the preparation and ease transfer process of highly aligned polymeric fibers	(Daulbaey, 2017)
Rotating wire drum electrospinning	Used for the preparation of thinner fibers	(Xu, 2017)
Rotating drum electrospinning	Provide a large area for the production of the large fiber	(Uspenskaya, 2021)
Wire Wounded drum collector electrospinning	Wires help in adjusting the area of polymeric fibers	(Prahasti, 2020)
Inside Sharpe pin rotating drum electrospinning	A technique used to fabricate the arrayed fibers	(Alghoraibi, 2018)
Ring collector electrospinning	Used to fabricate the twisted yarns	(Wei, 2018)
Coagulation bath electrospinning	Used to fabricate the long, aligned and continuous yarns	(Levitt, 2020)

Bio-Polymers

Biopolymers are the natural polymers that are found in the nature and those are not man made, all natural polymers are obtained from living organisms. Natural polymers normally exhibit the bio-compatibility and low immunogenicity, compared to synthetic and other polymers, when used in biomedical applications. The main reason for using natural polymers for electrospinning is their inherent capacity for binding the cells since they carry specific protein sequences, such as RGD (arginine/glycine/aspartic acid) However, partial denaturation of natural polymers is having high demand concern (Bhogale, 2018).



Bio polymers play an important role in food structure, food functional properties, food processing, and shelf life. The newly coming studies of food polymers regarding molecular design, synthesis, structure and property, materials preparation, and applications will give another directions to the food science and technology. The bio-polymers in food applications could provide a better food systems and improves the food qualities and safety. In these days, with the development of fundamental theories and analytical techniques that are related to polymers, especially the food polymers also having a rapid developing with the purpose of improving the food systems (Xingxun, 2015).

These polymers are cheaply available. They have good mechanical property, barriers for oxygen and vaporizable aromatic substances. Edible and biodegradable natural polymeric materials are one of the alternatives in food usage. Biodegradable natural polymeric materials can be used as edible films, coatings, packaging materials, carriers of antimicrobial and antioxidative materials (Radoslav, 2017).

Electrospinning is a technique to produce nanofibers from diverse polymers. Mainly biopolymers are often dissoluble in water and than electrospinning is an eco-friendly way. These materials, needs a crosslinking after-treatment to receive the desired amount of water-resistance. Other biopolymers are intrinsically water-stable and they do not need any crosslinking for other applications. This process of electrospinning of biopolymers, is blended with other biopolymers or man-made polymer (Ehrmann, 2020) s.

Synthetic Polymers

Synthetic polymers are manmade polymers they are usually derived from petroleum oil. These are classified as thermoplastics and thermosets. Thermoplastic polymers turn soft when they are heated and can be reversibly melted, whereas thermoset polymers undergo chemical reactions under heat or with chemicals forming insoluble materials that cannot be melted. Most synthetic polymers are organic in nature and are made up of carbon-carbon bonds. Elements such as oxygen, sulphur, and nitrogen are inserted to produce hetero polymers. They are also known as inorganic polymers. Synthetic polymers have many advantages over natural polymers as they can be tailored to give a wider range of properties such as, necessary mechanical properties such as viscoelasticity and strength and desired degradation rate (Zainudin, 2020).

Applications of Bio-polymers and Synthetic polymers in food industry

Packaging Material

Plastic materials obtained from oil such as polyolefins, polyesters, polyamides, polyethylene, polyvinyl alcohol, rubber latex, fluorocarbons, etc., are used for the materials food packaging. These polymers having good mechanical properties such as tensile, tear strength and also good barriers for oxygen and vaporizable aromatic substances, and for the transfer of gasses and water vapor and also, they can also be hot welded. The shelf-life of food products can be widely extended if edible casings and coatings made of polysaccharides, proteins and lipids. In present days Consumers want to purchase products that contain biodegradable materials (Petra, 2017). They are concerned about environmental problems caused by the disposal of non-renewable food packaging materials. And also interested in the use of renewable raw materials for food packaging and they are willing to increase usage of agricultural by-products. Application of Biopolymers in the Food Industry as extending their shelf-life. Packaging Films made from biopolymers work as barriers against the diffusion of moisture, gasses, and vaporizable aromatic materials and they can carry a great number of additives such as flavoring agents, antioxidants, vitamins, colorants, etc. Biodegradable films can contain different antibacterial agents such as nisin, lysozyme and organic acids like benzoic, sorbic, propionic, and lactic acid. They are used in the production of various food products such as cheese and meat products. This polymer helps to preserve the food and stop its deterioration (Schreiber, 2013).

Table 2: Below table contians different types of polymers and their applications in food packaging

Types of Polymers	Applications	Reference
Starch	Loose fill bags, films, trays and wrap films.	(Gonzalezand, 2013)
Cellulose	Flexible film	(Khwadia, 2010)
Bio-based PLA(Poly lactic acid)	Rigid containers, films and barrier coatings	(Jooyandeh, 2011)
Bio-based PET(Polyethylene terephthalate)	Bottles, trays and films	(Kemmer, 2017)
Bio-based PE	Rigid containers, films and barrier coatings.	(Mater, 2020)
PHA and PHB	Trays and barrier coatings.	(Joce, 2018)

Edible films and coatings

An edible film is a thin layer type of material that can be edible. It is found on the surface of some food products and it is also covers the product. It is said to be as a material used for food protection mainly in coating or films that extends the shelf-life of a product and does not need to be removed before consuming. An edible film is between 0.050 and 0.250 mm thick. Edible coatings have multiple functioning properties are

1. To stop the migration of substances in or out of a product mainly moisture, oxygen, carbon dioxide, flavors and other food ingredients.
2. To stop the loss of antioxidants, antimicrobials, and flavors.
3. To improve the mechanical integrity or handling methods of the food.

Biodegradable coatings are suitable for prolonging the shelf-life of food and increasing its quality of not causing pollution of the environment (Jooyandeh, 2011).

Edible coatings can be consumed together with food, providing additional nutrients and improving sensory characteristics and antibacterial properties. Due to the great number of polysaccharides which can be used as raw material for making coatings, edible polysaccharide-based coatings represent products with various characteristics. Collagen from meat, gelatin, whey proteins, zein from corn, proteins, and gluten from wheat are used to produce protein films. Edible coatings are very thin layers which are directly formed on the surface of food. Edible coatings can improve the physical properties and quality of food. In order to make a product attractive to consumers, edible coatings gives gloss finishing to the food that can be used to improve the features of a product. Edible packaging is widely used in the food industry day by day. Traditional coating methods are used for application of edible films, such as spray fluidization, falling and pan coatings, spraying, dipping, or brushing (Castejon, 2015).

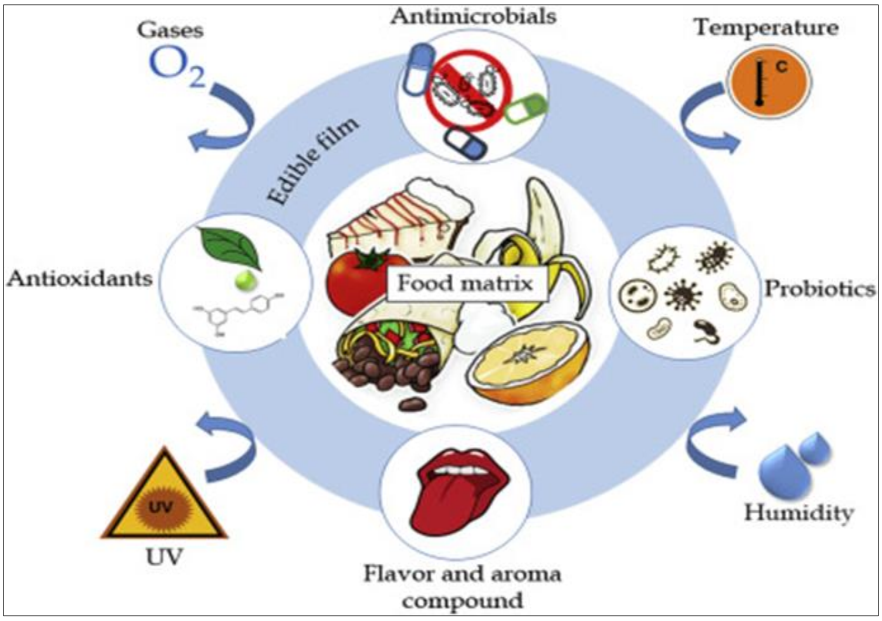


Fig 17: Edible films and coatings (kumar, 2020)

Antimicrobial films and active packaging

One of the upcoming ways to preserve food is to apply antimicrobial films to the surface of a product. The antimicrobial films and coatings are efficient in reducing the level of such pathogen microorganisms as Escherichia coli, Listeria monocytogenes, Salmonella Typhi and Staphylococcus aureus (Arancibia, 2015). Organic acids, enzymes, bacteriocins, peptides, polysaccharides and essential oils are incorporated into polymer coatings as antimicrobial agents. The most important benefit of antimicrobial edible films is that they may be used as inhibitors. They affect potential polluters on the surface of a product, and prevent their penetration inside the product. Polysaccharides, such as chitosan, creates strong films that can carry high levels of antimicrobial agents. Chitosan films that are made of hydrochloric, formic and acetic acids are hard and brittle, while other films that are made of lactic or citric acids are soft and elastic, which enables the production of multilayer coatings and wrappers. When they were prepared containing nisin and lysozyme, these films were inhibitory to gram-positive bacteria in both solid and liquid media, and when EDTA was added, gram-negative organisms were also inhibited. In present days a great number of natural polymers are used to form antimicrobial films from proteins such as whey protein, wheat gluten protein, soy protein, triticale protein, pea protein, fish protein (Sanchez, 2013).

In order to prepare antimicrobial films, at least one component that can form a suitable, continuous, cohesive and adhesive matrix must be included. Admixtures used to form antimicrobial films contain a film-forming agent, a solvent, plasticizers, a pH adjusting agent and an antimicrobial agent (Zinoviadou, 2010).

It is important to have the exact information about the types of microorganism when antimicrobial agents are selected in order to be the most efficient. Microorganisms are divided into several groups those are depending on oxygen, forming cell walls, depending on growth-stage or ideal growth temperature, and resistant to acid. Application of two or more agents that have weaker effects, but which are Application of Biopolymers in the Food Industry cheaper, can be extremely efficient in microorganism inhibition because of their complementary effects. Application of antimicrobial films and coatings needs to provide microorganism action after subsequent contamination, independent of previous food preservation and production processes for example, high temperatures or pressure. These films inhibit the action of the remaining microorganisms, it is not a matter how minute their number is. This is the way to lower the price of preserving food and make it safely. The antimicrobial films will be accepted and used in the food industry depending on existing regulations and the ratio between their purchase price and their efficiency after application (Storia, 2012).

Applications polymers in smart food packaging

Over the last decade, significant in the use of bio-polymers within the food industry as smart and active polymer systems has emerged. The polymers have been successfully utilized to entrap micro nutrients within micro particles and antioxidant packaging have been employed within food quality monitoring systems, such as active and intelligent packaging systems. The technologies which are associated with smart and active bio-polymers having the potential to drive the development of a new generation of intelligent and active packaging systems that integrate to food quality monitoring systems and micro particles that extends the shelf life of food products and their nutritional value (Stefani, 2016).

Conclusion

Electrospinning technique has been developed significantly during recent years. This method is also known as an efficient technique to produce nanofibers with high surface to volume ratio, absorbance capacity, porosity, and small pore size. The characters which are present those are making the electrospinning possible to be accompanied with different food spoilage indicators in an intelligent packaging. All of these advantages lead to quick response, easy-to-visualize, and real-time monitoring of food materials. The intelligent packaging possessing by electrospinning, most of the packaging produced in recent years.

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