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REVIEW ARTICLE

Interfacial polymerization on microencapsulation

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Abstract: The process of microencapsulation involves the packaging of solid, liquid, or gaseous active ingredients inside another material in order to protect them from the external environment. As a result, the active component is referred to as the core material, and the surrounding material as the shell. This method has been used in many different industries, including printing, chemicals, and pharmaceuticals. This has led to a generalized interest in microencapsulation technology. This method involves the polycondensation (condensation polymerization) of two complementary monomers at the interface of a two-phase system, as the term "interfacial" suggests. The development of interfacial polymerization began in the late 1960s and by the mid-1970s, it was being used to produce microcapsules. One phase that contains a reactive monomer is dispersed into a second immiscible phase, to which another monomer is added. At the droplet surface (interface), both monomers react, creating a polymeric membrane. While a great deal of research has been published in the last half-century, very few have offered a thorough analysis of this technology. This contribution examines the chemical, physico-chemical, and physical aspects of interfacial polymerization microcapsule production. It offers a tool for comprehending and mastering this production technology, but it also offers suggestions for future process design advancements.

Keywords: Immiscible phases; Reactive monomers; Interfacial reaction; Core shell structure; Controlled release; Microsphere formation.

1. Introduction

A long-term, controlled release of chemicals is achieved through the technique of microencapsulation. One method of coating active ingredients with minuscule capsules is called microencapsulation. It's a novel technology that has been applied to flavors, acids, oils, vitamins, microorganisms, and pharmaceutical, agrochemical, and food industries, among others. One way to provide a persistent scent that releases gradually over time is to apply microcapsules containing essential oils to fabric surfaces.

Developed mainly towards the end of the 1960s, interfacial polymerization found widespread application in the production of microcapsules by the mid-1970s. The process involves adding another monomer to an additional immiscible phase that contains a reactive phase that contains monomers. The reaction of the two monomers forms a polymeric membrane at the droplet surface (interface)[1]. Over the past fifty years, a great deal of research has been published, but only a small number of them have provided a comprehensive analysis of this technology. This contribution covers the chemical, physico-chemical, and physical aspects of manufacturing interfacial polymerization microcapsules, as well as providing a tool for understanding and mastering this production method. It also makes suggestions for upcoming improvements to process design [2,3]. Combining two liquid phases is not the only way that interfacial polymerization occurs (Figure 1). Other methods include vaporizing the reactant with an inert gas stream to create a polymerization reaction at a stable aqueous interface on a hydrophobic substrate and vapor–liquid interfacial polymerization (VLIP) using supercritical CO2 to supply vapor phase reactant. Furthermore, by freezing interfacial polymerization, solid–liquid interfacial polymerization can be carried out. The reactant near the contact becomes more enriched as a result of the crystallization phenomenon. On the exterior of the crystals, a layer of oxidant and dopant monomer reactants forms concurrently with the solvents crystallizing. Pyrrole, the other monomer reactant, stays liquid and permits the formation of films along the crystals' surface [4,5].

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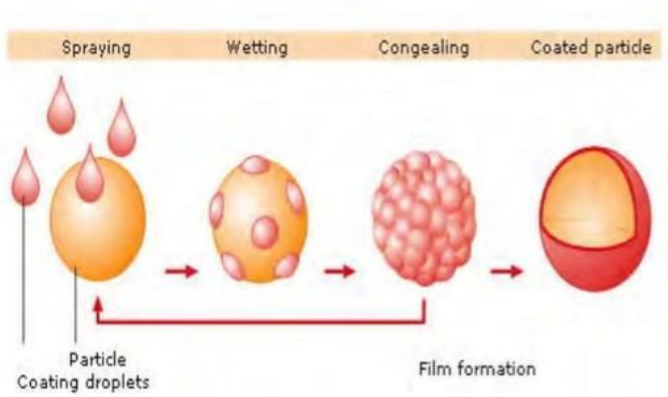

Figure 1 Various method of microencapsulation

2. Interfacial polymerization

2.1. Introduction

Interfacial polymerization can also happen when two liquid phases are combined. Alternative techniques involve vaporizing the reactant using an inert gas stream to initiate a polymerization reaction at a stable aqueous interface on a hydrophobic substrate, and employing supercritical CO2 to supply the vapor phase reactant in vapor–liquid interfacial polymerization (VLIP). It is also possible to perform solid–liquid interfacial polymerization by freezing interfacial polymerization. The crystallization phenomenon causes the reactant close to the contact to become more enriched. Parallel to the solvents crystallizing is the formation of a layer of oxidant and dopant monomer reactants on the outside of the crystals (Figure 2). The other monomer reactant, pyrrole, remains liquid and enables the surface of the crystals to form films [6].

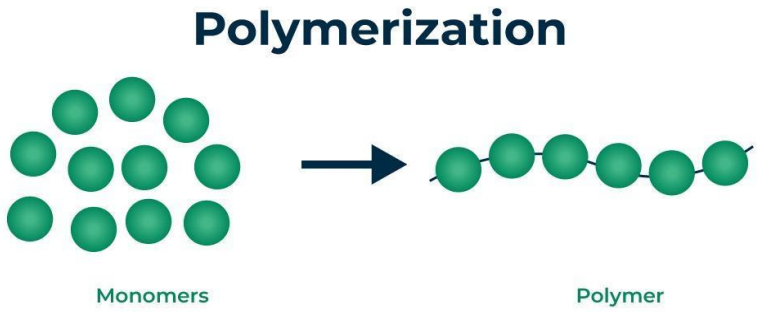

Figure 2 Polymers

2.1.1. Process

The original IP protocol involved is described below

- First, in an aqueous solution of a polymeric amine, soak the microporous polysulfone support.
- Second, in a solution of a diisocyanate in hexane, immerse the amine-impregnated membrane.
- Lastly, the membrane is cross-linked by performing a heat treatment at 110°C[7,8].

2.1.2. Core shell structure and interfacial reaction

Core–shell type nanoparticles are a type of biphasic materials which have an inner core structure and an outer shell made of different components. Transacylation is the most recent interfacial polymerization technique. Encasing active ingredients that might be vulnerable to oxidation or other forms of degradation is a great use for this encapsulation technique. Enzymes and living cells can be effectively encapsulated using it. This method forms the microcapsule wall by trans-polymerizing propylene glycol alginate macromolecules and acacia gum. Owing to its capacity for binding and emulsification, this complex polysaccharide finds widespread application in the food, pharmaceutical, and cosmetic sectors. Propylene glycol alginate is the other component that is used, which is produced when alginate is esterified with propylene glycol[9,10,11].

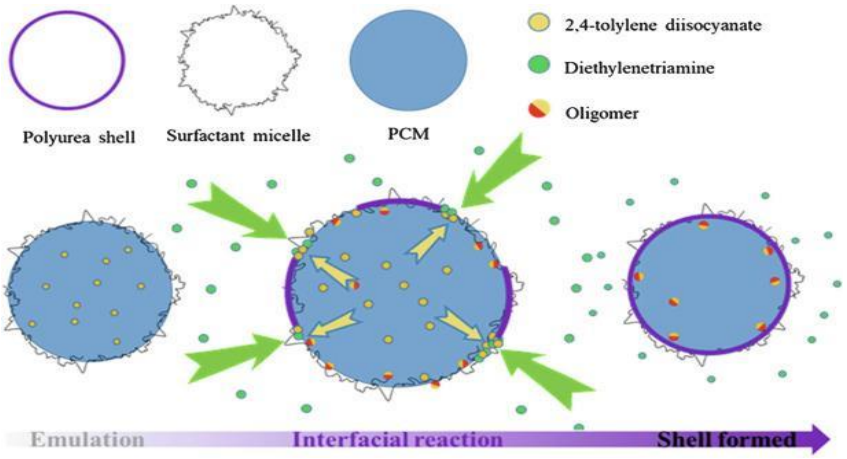

Figure 3 Interfacial reaction

2.2. Advantages

- Protection of volatile substances from untimely evaporation and prolongation of storage time.
- Protection of active substances against oxidation and during feed processing.
- Micro particles can protect the drug from the harsh environment in the body, which can result in degradation of the drug.
- Liquids can be transformed into solid micro capsules.
- The stability and shelf life of the drugs can be improved.
- Products with varied composition, quality and utility can be manufactured depending on the appropriate selection of the core coating material and microencapsulation technique .
- Dosage forms having controlled release characteristics can be formulated
- Owing to the small surface area of the microcapsules ,the drug moities are distributed over a large area ,thus enhances drug absorption[12,13].

2.3. Disadvantages

- Microencapsulation techniques are expensive .
- A single Microencapsulation technique cannot always be applied to encapsulate the same core material to produce different dosage form.
- The Shelf life of sensitive pharmaceuticals like hygroscopic drugs is reduced .
- Sometimes incomplete or non-homogeneous coating may result due to some inherent microscopic discontinuities of polymers.
- Microcapsules with non-uniform coating show non reproducible and unstable release characteristics [14,15,16].

3. Preparation of microencapsulation by interfacial polymerization

Through this process, distinct kinds of monomers combine to generate a polymer layer at the meeting point of two immiscible liquid phases. The polymer layer then envelops the dispersed phase. There is use of two monomers. While the other is dispersed and emulsified in the continuous phase, the first is entirely dissolved in the continuous phase, which is primarily water. Polymerization occurs when the two phases are mixed together because the monomers diffuse at the interface quickly[17,18]. The degree of polymerization is influenced by a number of variables, including the monomer's reactivity and concentration, reaction temperature, phase vehicle composition, etc.

The process of microencapsulation by interfacial polymerization entails enveloping a core material in a protective layer.

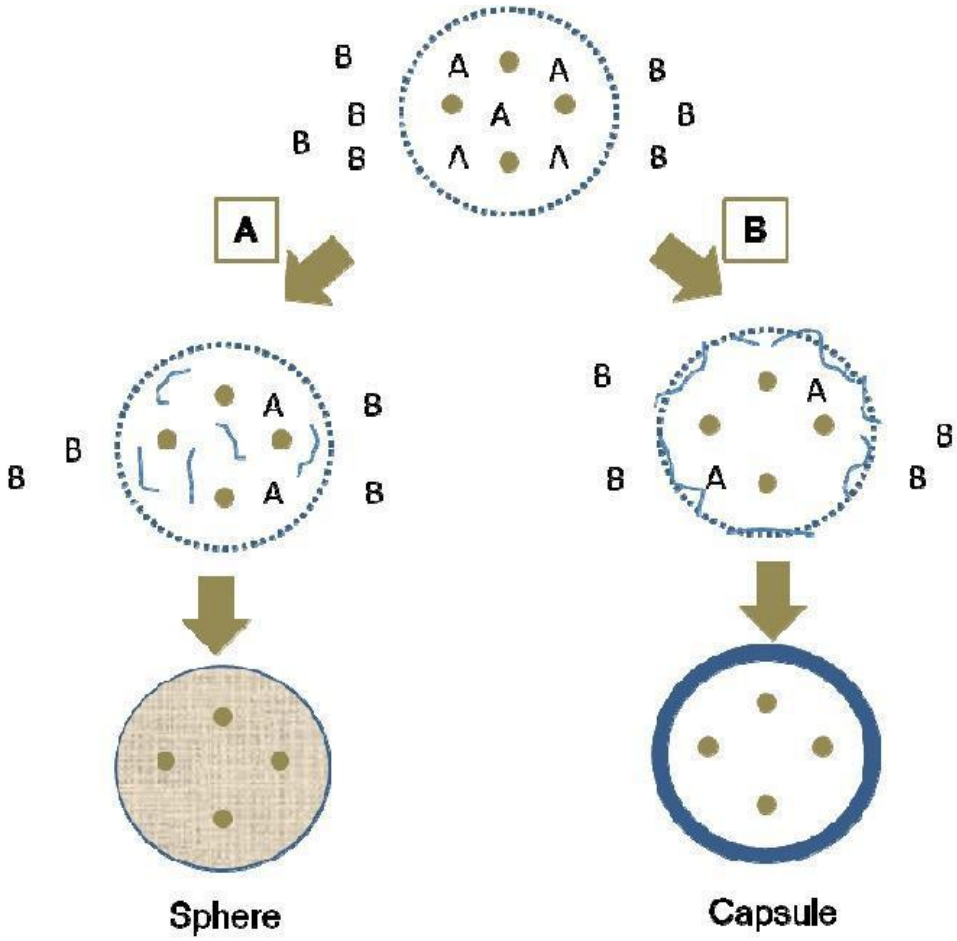

Figure 4 microencapsulation method

3.1.Steps involved in microencapsulation

3.1.1Materials

Gather core material and shell-forming monomers (e.g., polymeric isocyanates and polyamines), and a solvent.

3.1.2.Core Material Dispersion

Disperse the core material in a continuous phase using a suitable solvent. This forms droplets of the core material in the solvent.

3.1.3.Monomer Dispersion

Dissolve the shell-forming monomers in a separate phase, which will become the continuous phase during polymerization.

3.1.4.Contact Phases

Bring the two phases together, allowing the monomers to come into contact with the dispersed droplets. The monomers polymerize at the interface, forming a shell around the core material.

3.1.5.Polymerization

Initiate polymerization using a suitable catalyst or reaction conditions. This leads to the formation of a polymeric shell around each droplet, creating microcapsules.

3.1.6. Separation and Washing

Separate the microcapsules from the surrounding medium and wash them to remove any unreacted monomers or by products.

3.1.7. Drying

Dry the microcapsules to obtain the final product. Precision in reagent selection, reaction conditions, and thorough purification are crucial for successful microencapsulation by interfacial polymerization [19,20].

3.2.Microsphere formation

Polymeric microspheres are particles with a diameter of 1 to 1000 mudbugs can be delivered by encasing or trapping them in microspheres. Long-term and targeted drug release in the affected area are both accomplished with microspheres. A broad class of particulates with diameters in the high nanometer to micron range and spherical shapes, known as microspheres, are useful for a range of biomedical applications, including controlled drug release.

Four varieties of microspheres exist: Long-term delivery of therapeutic agents to the diseased site is made possible by bio adhesive microspheres with mucoadhesive properties that enable the drug-coated polymer surface to adhere to the targeted organ. Magnetic microspheres, which have applications in both medication delivery and diagnosis. An external magnetic source can be used to direct the drugs contained in these particles to the affected area. Furthermore, they are frequently employed in the treatment of magnetic hyper heat in tumor tissues. Meds placed within floating microspheres are intended to be released into the stomach. Particles that are radioactive and utilized in medicine. They attach themselves directly to the intended organ or tissue by injecting into the veins[21,22].

3.3.Mechanism action of microencapsulation

3.3.1.Microencapsulation Technology

Microencapsulation is the process of encasing microscopic particles or droplets in a barrier layer. To complete the process, a few techniques like coacervation, extrusion, or spray drying can be applied. The mechanism of action includes the controlled release, improved stability, and defense of the encapsulated material against external influences. This encapsulation provides benefits like targeted delivery, protection against degradation, and controlled release of chemicals in industries such as food, cosmetics, and pharmaceuticals. Depending on the formation method and state of the shell, microencapsulation can be done. Food ingredients can be microencapsulated using a variety of techniques to increase their bioavailability, solubility, and applicability while also overcoming some of their limitations. These methods include extrusion procedures, polymeric micelles, coacervation, liposomes, spray-drying, freeze-drying, and supercritical fluids [23].

3.3.2.Methods of microencapsulation

Methods of microencapsulation can be divided into physical methods, physico-chemical methods and chemical methods.

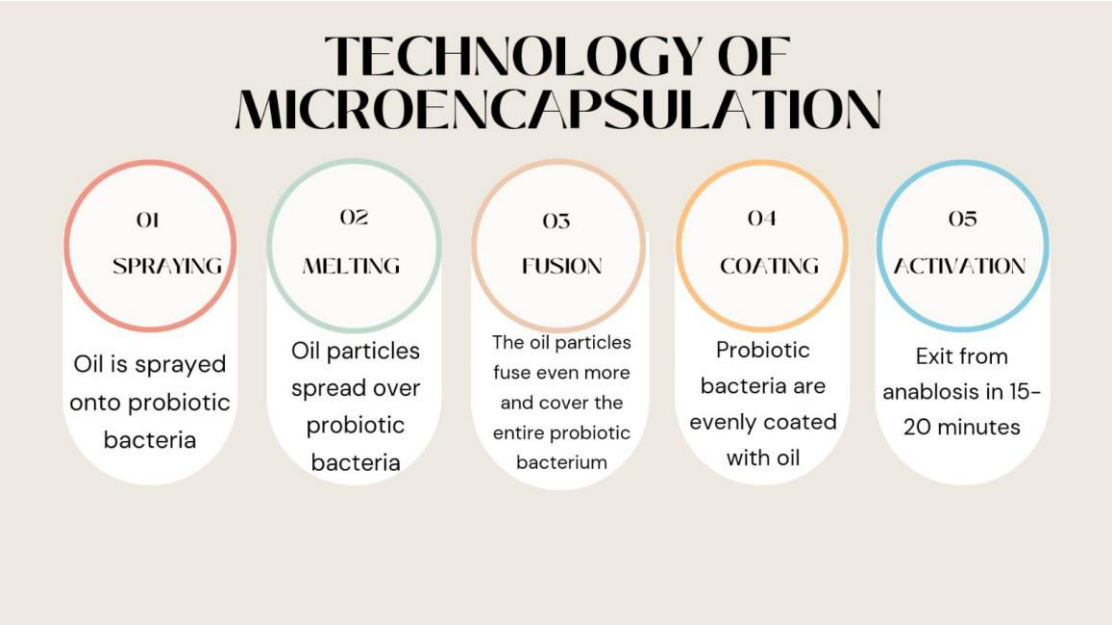

Figure 5 Technology of Microencapsulation

a. Physical methods

- Air suspension technique :Using this method, the wall material solution is sprayed on the fine solid core materials that are suspended by a vertical air current. The encapsulating material is deposited on top of the core material after the solvent has evaporated. To obtain the required film thickness, the procedures can be repeated. With this method, the core particles are typically large in size.
- Spray drying: When a hot gas comes into contact with atomized liquid feed, the droplets' solvent evaporates, leaving behind dried particles. This process is known as spray drying. The particles are then extracted from the drying gas using a bag filter or cyclone.
- Pan coating: The pan coating process is one of the oldest industrial methods for producing small, coated particles or tablets, and it is widely used in the pharmaceutical industry. While applying the coating material slowly, the particles are tumbling in a pan. The blower's pipe extends into the pot to distribute heat uniformly while the coating pan rotates[24].

b. Physico-chemical methods

Coacervation: By coacervation, aqueous colloidal solutions were separated into two liquid phases: one with a high colloid content (coacervate), and the other with a low colloid content. Coacervation is the term used to describe the separation of colloidal systems into two liquid phases (International Union of Pure and Applied Chemistry, 1997).

During coating, three immiscible chemical phases are created: the coating material is coated as a homogenous layer encircling suspended core particles after its liquid phase is first separated from a polymeric solution. The coating solidifies after that.

c. Chemical methods

Solvent evaporation**:** Solvent evaporation is a versatile method of particle preparation that makes a wide variety of drugs and macromolecules possible to use. During the solvent evaporation process, the medication is distributed or dissolved in the polymeric solution that is produced by dissolving the polymer in a suitable water immiscible solvent. In an aqueous continuous phase, the resultant solution or dispersion is further emulsified to produce discrete droplets.

Polymerization: Interfacial polymer: In interfacial polymerization, the two reactants in a polycondensation meet at an interface and react rapidly. In-situ polymerization**:** In-situ polymerization is a chemical encapsulation technique that resembles interfacial polymerization quite a bit. The distinguishing characteristic of in-situ polymerization is the lack of reactants in the core material. All polymerization occurs in the continuous phase, as opposed to interfacial polymerization, which occurs on both sides of the interface between the continuous phase and the core material. A demonstration of this method is provided by urea-formaldehyde [25,26].

3.4. Evaluation

The evaluation of microencapsulation carried out by:

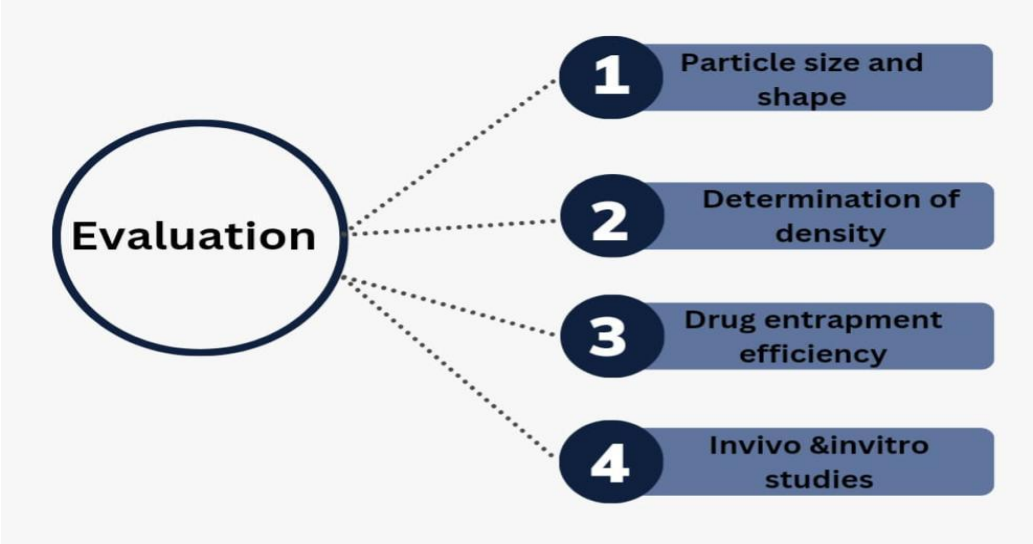

Figure 6 Evaluation of Microencapsulation

3.4.1.Particle Size Distribution

Examine the microcapsules' sizes to make sure they are within the range required for a given application.

3.4.2.Shell Thickness

Determine the coating's thickness around the core material, as this can affect the microcapsules' stability and release characteristics.

3.4.3.Morphology

To verify homogeneity and integrity, look at the microcapsules' external form and structure.

3.4.4.Stability

Evaluate the microcapsules' ability to withstand a range of environmental factors, such as temperature, humidity, and light exposure[27,28].

3.5.Applications

Microencapsulation based on interfacial polymerization is widely applied in various fields. In the pharmaceutical industry, one common use of controlled drug release is the encapsulation of active ingredients to enhance stability and control release rates. Moreover, it is employed in the food business to maintain sensitive components like flavors or vitamins, and in the textile sector to carefully release antimicrobial agents or dyes. This method is helpful in a number of industries, including cosmetics and agriculture, where controlled release and substance protection are required[29,30].

3.5.1.Pharmaceuticals

Medication delivery systems under control. Preventing the deterioration of delicate medications. Masking the taste of oral medications[31,32]

3.5.2.Food and Drink

Encapsulation of flavor for sustained flavor. preservation of components that are delicate. Nutrient release in functional foods is regulated.

3.5.3.Cosmetics and Personal Care

Fragrance in cosmetics is released under control. Safeguarding delicate cosmetic componentry. Encapsulation of sunscreen for extended efficacy.

3.5.4.Textiles

Antibacterial agents encapsulated in fabric. Scents released in textiles under control.

3.5.5.Agriculture

The regulated application of fertilizers or pesticides. Safeguarding agrochemicals from the elements.[33]

3.5.6.Biotechnology

Encapsulation of cells or enzymes for various applications. Controlled release of growth factors.

3.5.7.Coatings and Adhesives

Microencapsulation of catalysts for controlled reactions. Self-healing coatings through encapsulated healing agents.

3.5.8.Inks and Toners

Microencapsulated pigments for slow release in printing. Improved stability and shelf life of inks.

3.5.9.Fragrances and Perfumes

Controlled release of scents for longer-lasting fragrance. Protection of volatile fragrance compounds.

3.5.10.Environmental Applications

Encapsulation of bacteria for bioremediation. Controlled release of odor neutralizers. Microencapsulation provides a versatile approach for addressing challenges in different industries by encapsulating and protecting substances, controlling their release, and improving their stability [34,35].

4. Conclusion

One special technique for microencapsulation that offers precise control over the encapsulation process is interfacial polymerization. The method's ability to deposit thin, homogenous polymer coatings on micro-scale particles enhances the stability and performance of encapsulated materials. With more investigation and development, interfacial polymerization still holds promise for a range of uses, including food and medicine. As researchers continue to hone this technique, microencapsulation appears to have a bright future ahead of it, with advancements in controlled release, targeted delivery, and enhanced product performance.

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