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Review Article

Coating Tablets, Compositions, Recent Advancement and Current Status: A Comprehensive Review

Raj Kumar Mandal *[1], Paarth Saini [1], Rahul Pal [2], Prachi Pandey [3], Anshita Dubey [1]

[1]*Research Scholar, ISF College of Pharmacy (ISFCP), Moga, GT Road, 142001, Punjab, India.

[2] Assistant Professor, Department of Pharmaceutics, ISF College of Pharmacy (ISFCP), Moga, GT Road, 142001, Punjab, India.

[3] Assistant Professor, Faculty of Pharmaceutical Sciences, RAMA University, Kanpur, UP, India

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*Address for Correspondence:

Mr. Raj Kumar Mandal, Research Scholar, ISF College of Pharmacy (ISFCP), Moga, GT Road, 142001, Punjab, India.

Abstract

Conventional Tablets are solid oral dosage forms that contain an active pharmaceutical ingredient (API) along with excipients. These tablets are typically prepared through direct compression, wet granulation, or dry granulation. They are designed to disintegrate and release the API in a controlled or immediate manner, depending on the formulation. Tablet coating is a vital process in pharmaceutical technology, designed to improve the therapeutic efficacy, patient compliance, and stability of oral dosage forms. This comprehensive review explores the key aspects of tablet coating, including the types, compositions, and recent advancements. Coating materials such as polymers, plasticizers, and pigments are discussed in detail, along with their roles in controlling drug release, masking taste, and enhancing aesthetic appeal. The recent advancements focus on innovative coating techniques like film coatings, enteric coatings, and the application of nanotechnology to improve precision and functionality. Additionally, the current status of tablet coating is analyzed in terms of regulatory compliance and industry trends. The review highlights the future potential of personalized coatings, smart coatings, and environmentally friendly approaches, showcasing the evolving landscape of tablet coating technologies/pans in modern pharmaceutical manufacturing and development.

Keywords: Table coating; dosage form; enteric; coating pans; formulation; advancement; polymers.

1. INTRODUCTION

Tablet coating is a crucial technique in pharmaceutical development, significantly impacting the performance, stability, and aesthetic appeal of oral dosage forms. Over the years, coating technologies have evolved from traditional sugar coatings to more sophisticated approaches, such as film and enteric coatings, designed to modify drug release and enhance patient compliance [1]. Coating serves various functions, including protecting the active pharmaceutical ingredient (API) from environmental factors, masking unpleasant tastes or odors, and ensuring targeted drug delivery to specific regions of the gastrointestinal tract (GIT) [2-3].

The composition of tablet coatings typically involves a combination of polymers, plasticizers, colorants, and solvents. These materials are carefully selected based on the desired functionality, such as controlled-release, gastro-resistance, or immediate-release properties. Recent advancements have introduced innovative materials like biodegradable polymers and nanotechnology-based coatings, enabling more precise drug delivery and improved therapeutic outcomes[4]. In pharmaceutical science there are many different doses form which includes tablet, pills, bends, pallets etc. In which tablet is the most common pharmaceutical doses form. Due to its unique property that is easily administrable, conventional and economically. At initial level it is in powder form which is pressed to form a solid compressed dose. There are either prepared by compressing method or other method like moulding [5-6].

The primary benefit of tablets lies in their ability to provide a consistent dosage of the active pharmaceutical ingredient (APIs) that can be ingested. When discussing coated tablets, the term "coating" refers to a layer that is applied to the exterior of the tablet. This coating process involves enveloping the tablet in a thin layer of material, enhancing its surface [7]. Coating is a specialized method that applies a protective layer to the outer surface of the tablet. Once the coating material is introduced into a batch of tablets within a coating pan, the tablets acquire an additional layer. The various factors, such as spray

pattern, nozzle spacing, and droplet size, influence the coating technique employed. Tablet coating is an essential process in pharmaceutical manufacturing that adds both functional and aesthetic value to the final product. From basic film coating to advanced controlled- release systems, the coating technology ensures that the therapeutic benefits of the drug are maximized while meeting industry standards for quality and consistency [8-9]. The each coating type and technique must be carefully optimized to meet regulatory requirements and patient needs [10]

1.1. *Purpose of Coating:*

Tablet coating serves multiple essential purposes in pharmaceutical formulations. It masks unpleasant taste, odor, and color, while also providing physical and chemical protection from environmental factors such as oxygen, moisture, and light [11]. Coating shields the drug from gastric conditions, improving its stability and enhancing patient compliance by making tablets easier to swallow, particularly for large doses. It also improves tablet appearance, aids in brand differentiation, prevents tablet sticking during manufacturing, and prolongs the shelf life of volatile ingredients. The coating follows the fine contours of embossed logos, allowing for tablet printing, and enhances the physical strength of the tablets [12-13]. Additionally, it plays a critical role in modifying drug release rates, such as sustained, delayed, or repeated release, prevents drug incompatibility, and increases the efficiency of packaging processes [14].

As per the report published in 2015th nearly 178 million were spent on the drug delivery system which will targeted to increase 310 million dollar by the year 2025.

1.2. *Principle of coating*:

The principle of coating of tablet is crucial for the formulation of dosage form. The principle of tablet coating involves the application of a thin, uniform layer of coating material onto the surface of tablets to achieve desired functional and aesthetic outcomes [15]. The process generally relies on the following key principles:

Atomization of Coating Solution: The coating material, typically in the form of a solution or suspension, is atomized into fine droplets through a spray system. This ensures uniform distribution of the coating over the tablet surface [16].

Tablet Movement: The tablets are placed in a coating pan or fluidized bed, where they are constantly agitated or tumbled to ensure even exposure to the coating spray. This movement also prevents tablet agglomeration.

Drying Process: As the atomized coating solution is sprayed onto the tablets, a heated air stream is passed over them. This facilitates the evaporation of solvents or water, leaving behind a dry, smooth coating film.

Build-up of Coating Layers: Multiple layers of coating can be applied in a controlled manner, depending on the desired thickness and functionality of the coating, such as for sustained or delayed drug release.

Adhesion: The coating material must have adequate adhesion to the tablet core, ensuring that the coating remains intact during handling, packaging, and ingestion [17-18].

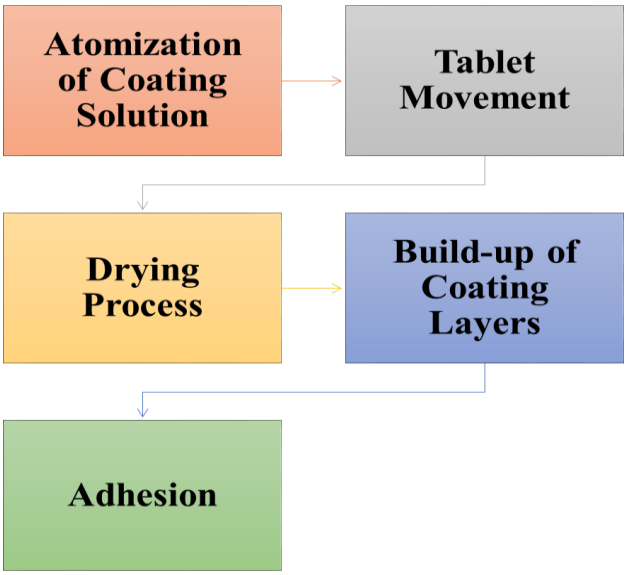

Figure 1: Representation of principle of tablet coating

These principles ensure the coating is uniform, functional, and tailored to the specific requirements of the pharmaceutical product.

1.3. *Defects/Problems Associated with Tablet Coating:*

The several defects and problems can arise during the tablet coating process, affecting the quality, functionality, and appearance of the final product. One common issue is picking and sticking, where tablets adhere to each other or to the coating equipment. This is usually caused by excessive coating solution or inadequate drying, resulting in uneven coatings [19]. Twinning is another defect that occurs when two or more tablets stick together, often seen in flat, round tablets due to their large surface area. The orange peel effect manifests as a rough, uneven surface resembling the texture of an orange peel, typically resulting from improper atomization of the coating solution or rapid drying. Blistering, which involves the formation of bubbles or blisters under the film coat, can occur due to the rapid evaporation of solvents, leading to weak adhesion between the coating and tablet surface [20]. The various defects related to coating tablet describe in the given **Table 1** as below.

Table 1: List of defects/problems associated with coating of tablet and suitable example [21-22]

Defect/ Problem	Causes	Remedies	Example
Picking & Sticking	High moisture content, excessive coating solution, or insufficient drying.	Optimize spray rate, increase drying air temperature, use anti-sticking agents.	Film-coated tablets with glossy surfaces.
Twinning	Flat, round tablets with large surface areas; low pan rotation.	Use biconvex tablets, increase pan rotation, reduce tackiness of coating solution.	Multivitamin tablets during film coating.
Orange Peel Effect	Improper atomization, high viscosity, or rapid solvent evaporation.	Adjust spray parameters, reduce viscosity, optimize drying conditions.	Delayed-release film-coated tablets.
Blistering	Rapid solvent evaporation or high coating temperatures.	Lower drying air temperature, adjust solvent system, increase drying time.	Enteric-coated aspirin tablets.
Cracking	Inadequate plasticizers, thick coating layers, or tablet expansion.	Use higher plasticizer content, apply thinner coatings, improve formulation.	Sustained-release tablets.
Chipping	Poor adhesion between coating and tablet, excessive mechanical stress.	Increase adhesion by adjusting binder content, improve handling and packaging processes.	Soft chewable tablets during coating.
Color Variation	Poor colorant distribution, improper mixing, or inadequate coating thickness.	Ensure uniform mixing of colorants, optimize coating thickness and application process.	Coated tablets with multiple color layers.
Erosion	Excessive coating solution or aggressive mechanical handling.	Reduce spray rate, optimize tablet hardness, minimize mechanical stress.	Thin-coated tablets sensitive to moisture.
Logo Bridging	Excessive coating thickness, poor flow of coating solution.	Adjust spray rate and solution viscosity, reduce coating thickness.	Coated tablets with brand logos.
Tablet Weight Variation	Uneven distribution of coating material due to improper spray rate or pan speed.	Calibrate spray guns, increase pan rotation speed for uniform distribution.	Large batches of coated drug tablets.

This table provides a structured overview of the common defects in tablet coating, along with their potential causes, solutions, and examples to better understand and troubleshoot the issues.

1.4. *Advanced Tablet Coating Techniques:*

Advanced tablet coating techniques have revolutionized the pharmaceutical industry by enhancing the functionality, precision, and efficiency of drug delivery systems. The innovation is film coating, which involves the application of a thin, polymer-based layer over tablets to modify drug release patterns, improve taste, and protect the active ingredients from environmental factors [23]. Enteric coating is another sophisticated method used to protect the drug from the acidic gastric environment, ensuring that the tablet dissolves only in the intestine, which is particularly useful for drugs sensitive to stomach acid or those that can cause gastric irritation [22-25].

Sustained-release and controlled-release coatings are designed to regulate the rate of drug release over time, offering extended therapeutic effects and reducing the frequency of dosing. These coatings often utilize specialized polymers that control dissolution rates. Nanotechnology-based coatings represent a cutting-edge advancement, where nanoparticles are integrated into the coating material to achieve targeted drug delivery, enhanced bioavailability, and improved therapeutic outcomes. Electrostatic coating is an innovative technique that applies a charged coating solution to tablets using electrostatic forces, ensuring uniform application with minimal waste. This method is particularly beneficial for achieving thin, precise coatings [26]. Lastly, multi-layer coating techniques allow for the application of multiple functional layers on a single tablet, each with a distinct purpose, such as immediate release followed by sustained release, or combining different APIs within the same dosage form. These advanced coating techniques contribute to improved patient compliance, enhanced drug stability, and the ability to tailor drug release profiles for specific therapeutic needs [27-28].

This review provides a comprehensive analysis of tablet coating compositions, exploring both conventional materials and cutting-edge innovations. It also discusses recent advancements, the current status of coating technologies in the pharmaceutical industry, and

emerging trends that promise to shape the future of tablet coating, including personalized medicine and environmentally sustainable solutions.

2. TYPES OF COATING TABLETS AND COATING MATERIALS

Coating materials used in tablet coating serve multiple purposes, such as protecting the drug from environmental factors, controlling the release profile, masking unpleasant taste, and improving the tablet appearance. The materials include polymers like HPMC for film coatings, enteric materials like cellulose acetate phthalate to prevent drug release in the stomach, and plasticizers to enhance flexibility [29]. Other additives may include pigments, flavoring agents, and anti-adherents. Coated tablets benefit from these materials by having enhanced stability, improved patient compliance, and tailored drug release, ensuring effective delivery of the active pharmaceutical ingredient. These coatings are essential in modern pharmaceutical formulations, making medication more efficient and user-friendly [28-30].

2.1. *Types of coating Tablet:* Coating:

Tablets are solid oral dosage forms that have a thin, protective or functional layer applied to their surface. The coating is used to enhance the tablet appearance, mask unpleasant taste or odor, protect the drug from environmental factors, control the release of the drug, and improve patient compliance. The coating can also serve a functional role in protecting the tablet active ingredients from gastric acid or ensuring targeted drug delivery to specific areas in the GIT [31]. They are generally classified as per their coating materials, these are as follows:

2.1.1. Enteric Coated Tablets: Enteric coated tablets are designed to resist the acidic environment of the stomach, allowing the tablet to dissolve and release its active ingredient in the more neutral pH of the intestines. This type of coating is particularly beneficial for drugs that are sensitive to gastric acid or that can cause irritation to the stomach lining. The enteric coating is usually made from polymers that swell or dissolve at higher pH levels, ensuring that the drug is protected until it reaches the desired site of absorption. This technology improves the BA of certain drugs and enhances patient compliance by reducing gastrointestinal discomfort [32].

2.1.2. Film Coated Tablets: Film coated tablets have a thin polymer-based layer applied to their surface, providing several advantages over traditional coatings. This coating not only enhances the tablet's appearance but also protects the active ingredients from moisture and light. Film coatings can be designed to control the release of the drug, allowing for sustained or modified release profiles. The application process is typically more efficient than sugar coating, resulting in a more uniform and precise layer that adds minimal weight to the tablet [32-33]. Additionally, film coatings can mask unpleasant tastes or odors, further improving patient compliance.

Film coating is a widely used technique in the pharmaceutical industry to enhance the functionality, stability, and appearance of tablets. It can be categorized based on the coating materials used, primarily into organic film coatings and aqueous film coatings.

Organic Film Coating: Organic film coatings are composed of synthetic polymers that are typically dissolved in organic solvents before application. These coatings provide a robust and durable protective layer around the tablet, offering advantages such as moisture resistance and improved mechanical strength. Common polymers used in organic film coatings include:

- **Hydroxypropyl Methylcellulose (HPMC):** Provides excellent film-forming properties and is widely used due to its biocompatibility.
- **Polyvinyl Alcohol (PVA):** Offers good adhesion and flexibility, making it suitable for various pharmaceutical applications.
- **Methacrylate Copolymers:** These are often used for enteric coatings and sustained-release formulations due to their ability to control drug release based on pH and time.

Organic film coatings are advantageous for their ability to create a uniform, glossy finish, enhance the taste masking of bitter drugs, and provide controlled release properties. However, their use of organic solvents may raise concerns regarding environmental impact and the potential for residual solvent in the final product [34-35].

Aqueous Film Coating: Aqueous film coatings are formulated using water as the primary solvent, making them more environmentally friendly compared to organic coatings. These coatings utilize water-soluble polymers, allowing for a safer and more efficient application process. Common polymers used in aqueous film coatings include:

- **Polyvinyl Pyrrolidone (PVP):** Known for its excellent solubility and film-forming properties, often used in taste-masking applications.
- **Cellulose Derivatives:** Such as hydroxypropyl cellulose (HPC) and HPMC, which provide good film strength and flexibility.
- **Natural Gums:** Such as xanthan gum and guar gum, which are used for their biodegradability and biocompatibility [36].

Aqueous film coatings offer several benefits, including reduced solvent exposure, easier processing, and the potential for better drug release profiles. They also help maintain the stability of sensitive APIs. However, the film may be less robust compared to organic coatings, depending on the formulation and processing conditions.

2.1.3. Sugar Coated Tablets: Sugar-coated tablets are among the oldest forms of tablet coatings, where a multi-layer coating of sugar, colorants, and polishing agents is applied to the tablet core. This process results in a glossy finish that enhances the aesthetic appeal of the tablet and helps mask unpleasant tastes or odors [37]. However, sugar coating is a labor-

intensive process that can significantly increase the size and weight of the tablet. Although they are less commonly used in modern formulations due to the efficiency of film coatings, sugar-coated tablets remain popular for certain applications, especially in over-the-counter medications aimed at a broader consumer audience.

Another, sustained or controlled release coated tablets are designed to release the drug slowly over an extended period, providing prolonged therapeutic effects by utilizing polymers and other materials that regulate the dissolution rate, thereby reducing the need for frequent dosing. Modified release coated tablets aim to alter the timing and rate of drug release, encompassing both delayed-release formulations, such as enteric-coated tablets, and extended-release formulations, allowing for flexible control over the absorption of the drug in the body. Additionally, compression coated tablets involve compressing a dry coating around the tablet core, offering protection and enabling controlled release, making this technique particularly useful for formulations containing two incompatible drugs or those requiring delayed release of the active ingredient [38-39].

Together, these various coating types serve essential pharmaceutical purposes, enhancing drug stability, ensuring precise drug delivery, and improving the overall patient experience.

2.2. *Coating Materials:*

Coating materials are essential in tablet formulation, influencing the stability, release profile, and overall performance of the final product. The primary components include polymers such as HPMC and EC, which provide film-forming properties and flexibility. Plasticizers like glycerin and triethyl citrate enhance the elasticity of the coating film. Colorants, such as titanium dioxide and iron oxides, improve the aesthetic appeal and brand differentiation of tablets. Surfactants are added to enhance wetting properties, while antioxidants protect active ingredients from degradation. Solvents, either aqueous or organic, are used to dissolve these components during the coating process [40]. Together, these materials ensure effective drug delivery, improve patient compliance, and enhance the overall quality of coated tablets. The various coating materials of tablet coating mentioned in the given **Table 2** as below.

Table 2: List of coating materials with suitable examples used in the tablet coating [41-42]

Coating Type	Coating Materials	Examples
Film Coating	- Polymers: HPMC, Polyvinyl alcohol (PVA), Ethyl cellulose (EC). - Plasticizers: Glycerin, Polyethylene glycol (PEG), Propylene glycol. - Colorants: Titanium dioxide, Iron oxides.	- HPMC: Provides a thin, protective film for controlled release. - PVA: Flexible, transparent film, used for taste masking. - Titanium dioxide: Used as a white pigment for improving tablet appearance.
Enteric Coating	- Polymers: Cellulose acetate phthalate (CAP), Hydroxypropyl methylcellulose phthalate (HPMCP), Methacrylate copolymers. - Plasticizers: Triethyl citrate, Dibutyl sebacate. - Acid-resistant agents: Methacrylic acid.	- CAP: Used to resist stomach acid, releasing the drug in the intestine. - HPMCP: Offers acid protection and delayed release. - Methacrylate copolymers: Common for enteric and sustained release formulations.
Sugar Coating	- Sugars: Sucrose, Glucose. - Colorants: Titanium dioxide, Lakes and Dyes. - Polishing agents: Beeswax, Carnauba wax.	- Sucrose: Forms a thick, glossy layer to mask taste and improve appearance. - Beeswax: Adds shine and smooth finish to the coated tablets. - Titanium dioxide: Provides opacity and aesthetic appeal to sugar-coated tablets.

This **Table 2** illustrates the different coating materials used for film, enteric, and sugar coatings, along with their examples and specific roles in pharmaceutical applications

2.3. *Steps Involved in the Tablet Coating:*

Tablet coating involves several critical steps that ensure the uniform application of the coating material, leading to the desired release characteristics, stability, and appearance of the tablets [43]. The several steps involved in the Tablet coating mentioned in the given **Fig. 2** as below following.

Figure 2: Representation of steps of tablet coating and tablet finished products

Initially, the coating solution is prepared by dissolving coating materials such as polymers, plasticizers, and colorants in a suitable solvent, either aqueous or organic, with adjustments made to achieve the desired viscosity and flow properties. Next, tablets are loaded into a coating pan or fluidized bed coater, allowing for even distribution of the coating solution over their surfaces. The coating solution is then sprayed onto the tablets as they rotate or are suspended, with the spray nozzle atomizing the solution into fine droplets for uniform coverage. After spraying, the coated tablets are dried to remove the solvent, with hot air circulated in coating pans or warm air passing through fluidized bed coaters to ensure proper adhesion and integrity of the coating [44]. Following drying, the tablets are cooled to ambient temperature to stabilize the coating and prevent condensation. QC checks are conducted to assess the uniformity, appearance, and performance characteristics of the coating, including film thickness, adhesion, and release profile. Finally, once the tablets pass quality control, they are packaged for distribution, protecting them from environmental factors and ensuring stability during storage and transport [45-46].

3. COATING MACHINES INVOLVED IN COATING OF TABLETS

Coating machines play a vital role in the tablet coating process, ensuring uniform application of the coating material to enhance the tablet's appearance, stability, and functionality. The most commonly used machines include traditional pan coaters, where tablets rotate in a perforated or non-perforated drum while the coating solution is sprayed onto them [47]. Fluidized bed coaters are also widely used, where tablets are suspended in an air stream, allowing for even coating from all directions. Modern advancements have led to the development of automated high-efficiency coaters, which provide precise control over coating thickness, drying time, and airflow, optimizing the entire process. These machines ensure consistent coating quality, improve production speed, and minimize wastage of coating materials [48-49].

3.1. *Types of coating pans:*

The various coating pans used in the coating of tablet on the basis of their coating materials as well, they are as follows:

3.1.1. Conventional Coating Pans

Conventional coating pans are one of the earliest methods used in pharmaceutical industries for coating tablets or pellets. They consist of a large rotating metal pan, usually made of stainless steel, in which the core tablets or pellets are placed. The coating solution, typically a sugar or film coating, is applied as the pan rotates, allowing the material to spread uniformly over the surfaces. Heated air is directed into the pan to dry the coated particles, ensuring proper adhesion and preventing sticking. Although effective, conventional coating pans have slower process times and may result in uneven coating compared to more modern techniques [50].

A conventional coating pan, also known as a standard coating pan, is a circular metal pan inclined at a 40- degree angle, with diameters ranging from 8 to 60 inches. It rotates on its horizontal axis, driven by a motor. Heated air is supplied through an inlet to prevent sticking, while an exhaust removes dust. The coating solution is applied to the tablets either by ladling or spraying, and an atomizing system ensures even distribution of the coating solution across the tablet surfaces [51-52]. The several coating pans used in the sugar and also used in the film coating with some modification brands as follows (**Table 3**):

Table 3: List of coating pans types, their features and limitations [52-54]

Coating Pan Type	Features	Limitations	Additional Systems
PelligRini Coating Pan	- Typically used for sugar coating, with batch ranges from 10 to 1000 kg.	- Not suitable for film coating due to drying limitations.	- Glatt impression sword air handling system improves drying efficiency.
Glatt Impression Sword Coating Pan	- Two systems for hot air and exhaust: a) PLG system: Hot air inlet through sword, exhaust via plenum. b) Hot air through plenum, exhaust via two perforated swords.	- No significant limitations reported.	- Enhanced drying efficiency with air management systems.
Immersion Tube Coating Pan	- Equipped with a long tube with a spray nozzle at the tip. - Hot air passes through the tube into the tablet bed, while dried air flows upward and exhausts via dust control.	- None specified.	- Known for rapid processing of both film and sugar coatings.

Their basic design requires manual interventions, and they often face challenges with drying, especially when used for modern film coatings. However, improvements like the installation of air-handling systems (such as the Glatt impression sword) have enhanced their functionality [55]. While they remain suitable for traditional processes, advanced coating technologies are preferred for more precise and efficient coating requirements in contemporary formulations.

3.1.2. Perforated Coating Pans

Perforated coating pans are modern systems designed to improve the efficiency and uniformity of tablet coating processes. These pans have perforations along their surface, allowing heated air to pass directly through the tablet bed during rotation. This design enhances the drying process by ensuring better airflow and reducing the risk of tablet sticking or uneven coating. Typically used for both sugar and film coatings, perforated pans offer more precise control over coating parameters and are suitable for a wide range of batch sizes. They are more efficient than conventional coating pans, providing faster and more consistent results [56].

The perforated coating pan is another type of coating equipment featuring a partially or fully perforated drum that rotates on its horizontal axis, all while being enclosed in a sealed housing. As tablets rotate within the perforated pan, the design enhances drying efficiency. The coating solution is sprayed onto the tablets while warm air circulates through the perforations, ensuring even coating and effective drying [57]. These pans are ideal for film and enteric coatings, offering better control over coating quality and drying compared to traditional pans, making them superior for modern coating processes. The several coating pans used in the sugar and also used in the film coating with some modification brands as follows (**Table 4**):

Table 4: List of perforated coating pans with their types, features and uses [58-59]

Coating Pan Type	Features	Air Flow Systems	Uses
Accela Coat Pan	- Fully perforated pan with mixing blades. - Inlet air enters via a plenum in contact with the top of the pan. - Exhaust air is removed through a plenum below the pan.	- Air inlet by top plenum. - Exhaust by bottom plenum.	Commonly used for efficient film coating.
Dumoulin IDA.X. Coating Equipment	- Fully perforated cylindrical central section. - Two air plenums for inlet/exhaust located outside the pan. - A third plenum directs inlet air onto the product surface through a slotted tube.	- Single flow. - Reversed single flow. - Double flow. - Direct double flow.	Film and enteric coating with customizable air flow.
Glatt Pan-Coating Equipment	- Similar to Accela Coat. - Divided air plenum beneath tablet bed for inlet/exhaust. - Additional air plenum above door for extra air inlet/exhaust. - Expensive equipment.	- Air blown into/exhausted from pan through divided sections. - Additional air plenum for more control.	Used for high-precision film and enteric coating processes.
Hi-Coater Pan	- Four perforated segments, perpendicular to each other. - Perforations serve as air outlets fixed to pan's exterior. - Drying air introduced through an opening at the top of the pan.	- Air introduced through top opening. - Exhaust through perforations.	High-efficiency film and enteric coating.
Dria Coater	- Drying air introduced through hollow perforated baffles along the drum's inside periphery. - Exhaust from the back of the pan. - Multiple air flow configurations.	- Direct flow: Air in at top, exhaust through baffles under tablet bed. - Reverse flow A & B for varying air direction.	Flexible air flow for various coating needs.
Hüttlin Butterfly Pan	- Large, angled, slotted openings at the junction of cylindrical section with front/back panels. - Drying air applied by a Mear tube onto product surface. - Hinged front and back for easy access.	- Air exhaust through large slotted openings. - Drying air applied from above.	Film and enteric coating, widely used in pharmaceutical industries.

Perforated coating pans offer a significant advancement over traditional coating pans, providing better control over the coating process, improved drying efficiency, and more uniform coating distribution. Their design allows for the effective circulation of heated air through perforations, which enhances both film and enteric coating applications [60]. These systems support a variety of air flow configurations, making them ideal for modern pharmaceutical formulations where precision and efficiency are essential.

3.1.3. Fluidized bed Coating Pans

Fluidized bed coating pans are advanced systems used in the pharmaceutical industry to apply coatings to tablets and granules. In this technique, the product is suspended in an upward-moving stream of air, creating a fluidized state that allows for uniform coating application. The coating solution is sprayed onto the fluidized particles, where it adheres evenly due to the constant movement and mixing facilitated by the air flow. This method not only ensures consistent coating thickness but also enhances drying efficiency, as the air helps evaporate the solvent quickly [61-62]. Fluidized bed coating is particularly effective for film and enteric coatings, providing high- quality results in a shorter processing time compared to traditional methods.

In fluidized bed coating pans, the fluidization technique is employed, where air suspends and fluidizes tablets or granules, creating a uniform bed. As the particles move within the air stream, the coating solution is sprayed onto them, ensuring even distribution. Simultaneously, hot air dries the particles in real time, preventing agglomeration and allowing for effective coating [63]. This type of equipment is widely used in the pharmaceutical, chemical, and food industries for coating granules, pellets, or powders, making it ideal for applications such as controlled-release drug formulations and protective coatings.

Principle of Operation:

- **Fluidization:** Particles to be coated are suspended in an air stream, which causes them to behave like a fluid. This ensures that each particle is evenly exposed to the coating solution.
- **Spraying:** While the particles are suspended, a coating solution (often a polymer dissolved in a solvent or water) is sprayed into the bed. The solution adheres to the particles.
- **Drying:** The hot air used for fluidization also evaporates the solvent or moisture in the coating solution, leaving behind a uniform layer on the particle surface [64-65].

Types of Fluidized Bed Coating Processes: They are as following mentioned **Table 5**.

Table 5: List of types of FBC Process and their description [65-66]

Type of Fluidized Bed Coating Process	Description
Top-Spray Coating	The spray nozzle is positioned above the fluidized particles, commonly used for granulation and coating processes.
Bottom-Spray Coating	The spray nozzle is located at the bottom, applying coating as particles are pushed upwards by the air stream; ideal for controlled-release coatings.
Tangential Spray	The nozzle is positioned at an angle to the bed, used for applying high-load coatings.

3.2. *Factors Affecting Tablet Coating:*

Tablet coating is a critical process in the pharmaceutical industry, influencing the quality, performance, and stability of the final product. The several factors can affect the coating process, including:

- **Coating Solution Properties:** The viscosity, surface tension, and concentration of the coating solution impact its ability to adhere to the tablet surface and form a uniform film. A higher viscosity may lead to uneven coating, while inadequate surface tension can hinder adhesion.
- **Tablet Characteristics:** The size, shape, and surface roughness of the tablets influence how well the coating adheres. Tablets with irregular surfaces may require adjustments in the coating process to ensure uniformity.
- **Process Parameters:** The operational parameters such as spray rate, air flow rate, and pan speed can significantly affect coating efficiency. For instance, a higher spray rate may result in thicker coatings, while an increased air flow can enhance drying and reduce the risk of sticking.
- **Equipment Design**: The design of the coating equipment, including the type of coating pan and the spray nozzle configuration, plays a crucial role in determining the uniformity and quality of the coating.
- **Tablet Core Properties:** Tablets need to be hard and have good friability to avoid breakage during the coating process [67-68].

Fluidized bed coating pans are widely used when uniform, high-quality coatings are needed on particulate materials. The various coating technologies, such as conventional pans, perforated pans, fluidized bed systems, and modern spray-coating techniques, each offer unique advantages and can be tailored to specific coating requirements. Factors such as the properties of the coating solution, tablet characteristics, process parameters, and environmental conditions significantly influence the effectiveness and uniformity of the coating process [69]. By understanding these machines and the factors affecting coating, manufacturers can optimize production efficiency and ensure consistent product quality.

4. RECENT AND MARKEED APPROCHES ON TALET COATING

Tablet coating has evolved significantly with the advent of modern technologies and innovative materials, offering better control over drug release, stability, and patient compliance. Recent approaches in tablet coating focus on improving functional performance, such as controlled-release, taste masking, and protection from environmental factors like moisture and light [70]. Techniques like enteric coating, which allows drug release in the intestines instead of the stomach, and film coating, using polymers for uniform and fast application, have gained popularity.

4.1. *Prepared Marketed Coated:*

Advances in coating materials, including biodegradable polymers and nanocomposites, have further enhanced the efficiency and safety of coatings. The several prepared marketed coated tablets, with their suitable details and their characterization mentioned in the **Table 6** as below following.

Table 6: List of several brands, types of coating, uses and manufacturer

Brand	API/Drug	Coating	Application/Uses	Manufacturer	Ref.
RTCID-DSR	Rabeprozole sod.+Domperidone	Enteric coating	Peptic Ulcer	Servo Sanitus Remidie	[71]
CIRROMSAM-400	Ademetioine		Treat liver Disease	Winista pharma	[72]
DUCOLAX	Bisacodyl		Constipation	Mediflora Pharmacy	[73]
Mycept-S360	Mycophenolate		Immuno-suppressant	Vijay life care	[74]
Dropsid-DSR	Esomeprazol+ Domperidon		Acid reflux	Sawarag pharmaceuticals	[75]
Pivikto	Alpelisib	Film coating	Breast cancer	Vijay life science	[76]
Votrient 400mg	Pazopanib HCl		Anti-cancer for kidney	RRT Pharma	[77]
KRYXANA	Ribociclib		Anti-cancer	Greensoul Remedies	[78]
Mofilet	Mycophenolate	Sugar coating	Immuno-suppressant	Medwell India Care private limited	[79]
CAPINEM	Ethomsylate & Transcinamic acid		Prevent mentrual bleeding	Aileran	[80]

4.2. *Characterization of Marketed Products:*

Characterization of coated tablets involves a comprehensive evaluation of the physical, chemical, and mechanical properties of the tablet's coating to ensure its quality and functionality. This process is critical to determine whether the coating meets the desired specifications, such as uniformity, thickness, and adhesion [81]. Various analytical techniques are employed, including microscopy for surface morphology, spectroscopy for chemical composition, and dissolution testing to assess the release profile of the active ingredient. Mechanical tests, such as hardness and friability, ensure the coating provides adequate protection while maintaining tablet integrity [82]. Additionally, thermal analysis and moisture permeability tests are used to evaluate the stability of the coating under different storage conditions. The characterization of coating tablet mentioned in the **Table 7** as below.

Table 7: List of characterization of coating tablets with specified APIs

API/Drug	Types of Coating	Disintegration time (min)	Dissolution Rate	Hardness (kg/cm²)	Friability (%)	Ref.
Diclofenac Sodium (DCS)	Film coating	8-10	14% in 5 hrs.	8.4	0.10	[83]
Pantoprazole		8(pH 6.8)	90 min	8	0.2	[84]
Clarithromycin		2.16	95.45 in 15 min	10	-	[85]
Secnidazole		18min	97.87%	5kg/cm2	Low with in rang	[86]
Diltiazem	Enteric coating	13.33	95.12(pH6.8) 240 min	6	0.7	[87]
Azithromycin		100	120	4.58	0.5	[88]
Diclofenac sod.		4-5	96.5 in 45 min	3.5-4.5	Less than 0.6	[89]
Esomeprazole		11.35	115.5	-	-	[90]
Placebo		70.25(6.8) min	115.5+_7.5	3.5-4.5kg/m2	0.6	[91]
Mesalazine		218..65+-98ml	Ph6.8 96.53%kg/cm2	6.4+_0.3kg/cm2	0.15%	[92]
p-amino salicylate Sodium		7.1+_0.41	98.3+_1.02	8.1+0.2kg/cm2	0.15	[93]

These characterization methods help in optimizing the coating process, ensuring consistency in drug delivery, and enhancing the shelf life and effectiveness of the final pharmaceutical product. Moreover, the use of automated spray coating processes and the development of coating formulations tailored for specific drug properties have made tablet coating a precise and indispensable tool in pharmaceutical manufacturing [94]. These marked innovations and characterizations ensure the tablet's therapeutic efficacy and improve patient adherence by making oral medication more effective and user-friendly.

5. CURRENT CHALLENGESS AND FUTURE PROSPECTIVE

The current challenges in tablet coating technology are multifaceted and impact the efficiency, quality, and regulatory compliance of pharmaceutical products. One significant challenge is achieving uniform coating thickness, which is crucial for consistent drug release profiles; variations can arise from inconsistent spray techniques or equipment performance. Additionally, the development of novel coating materials often faces hurdles in scalability and reproducibility, complicating the transition from laboratory formulations to mass production [95]. The future of tablet coating technologies is set to evolve dramatically, reflecting ongoing innovations in materials science, engineering, and pharmaceutical applications (**Fig. 3**). As research continues to advance, several key trends and prospects can be anticipated in the realm of tablet coatings, compositions, and their applications:

Enhanced Drug Delivery Systems: The development of novel coating materials and techniques will lead to more sophisticated drug delivery systems, such as multi-layer coatings that can provide controlled release and targeted delivery. This will enable better management of chronic diseases, allowing for precise dosing and improved patient compliance [96].

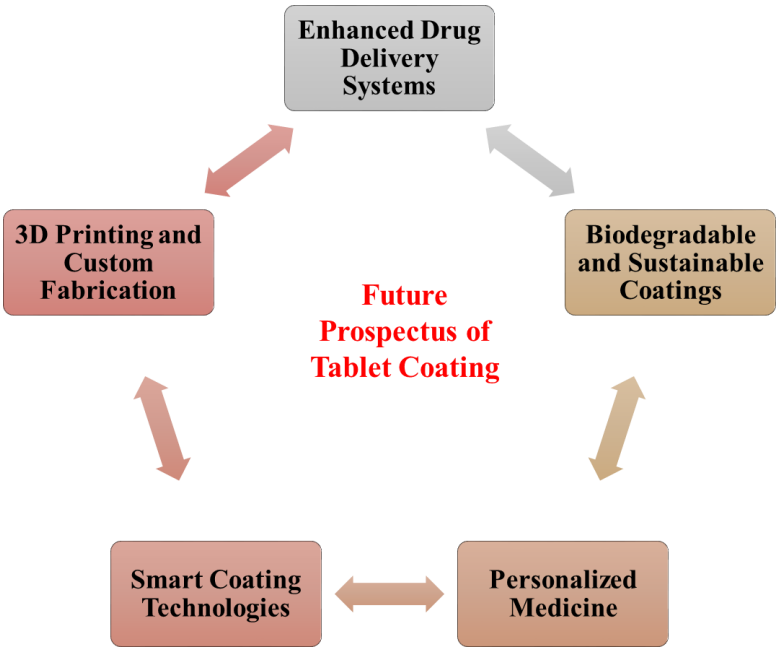

Figure 3: Representations of future prospectus of tablet coating

Biodegradable and Sustainable Coatings: As the pharmaceutical industry faces increasing pressure to adopt sustainable practices, the future will likely see a shift towards biodegradable and environmentally friendly coating materials. Innovations in natural polymers and green chemistry will reduce the environmental impact of coatings while maintaining or enhancing their performance.

Personalized Medicine: The move towards personalized medicine will significantly influence the design and application of tablet coatings. Customized coatings that adapt to individual patient profiles will facilitate tailored drug release mechanisms, optimizing therapeutic outcomes and minimizing adverse effects.

Smart Coating Technologies: The integration of smart technologies, such as stimuli-responsive coatings that react to specific physiological conditions (e.g., pH changes or temperature variations), will enhance the functionality of coated tablets. These advancements could improve the efficacy of medications by ensuring precise release at targeted sites within the gastrointestinal tract.

3D Printing and Custom Fabrication: The application of 3D printing technology in tablet coating will revolutionize pharmaceutical manufacturing by allowing for the precise fabrication of complex geometries and personalized formulations. This could enable on-demand production of tailored coated tablets, reducing waste and improving efficiency [97-98].

The future of coating tablets encompasses a myriad of possibilities that promise to enhance drug delivery, improve patient adherence, and reduce environmental

impacts. As research and technology continue to progress, the pharmaceutical industry will be well- equipped to meet the evolving needs of healthcare, ultimately leading to better health outcomes for patients worldwide [99-100]. Addressing these issues will require ongoing research, technological innovation, and collaboration across the pharmaceutical industry.

CONCLUSION

In conclusion, the evolution of tablet coating has significantly enhanced the pharmaceutical industry by improving drug delivery systems, ensuring stability, and enhancing patient compliance. This comprehensive review highlights the various coating compositions, from traditional sugar and film coatings to advance polymer- based and nanocomposite coatings. Recent advancements, such as targeted release formulations, improved mechanical properties, and eco-friendly coating materials, reflect the industry's commitment to innovation. The current status of tablet coating underscores its pivotal role in pharmaceutical development, offering precise control over drug release profiles and protection against environmental factors. As technology progresses, the future of tablet coating will continue to drive improvements in drug efficacy and patient care.

List of Abbreviations

API: Active Pharmaceutical Ingredients; HPMC: Hydroxypropyl methylcellulose

Ethical Approval

Not applicable.

Consent for Publication

Not applicable.

Human And Animal Ethical Right

Not applicable.

Conflict of Interest

The authors declare no conflict of interest, and no funding was required to conduct these review data.

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Availability of Data and Materials

The data supporting this study’s findings will be available in the cited references.

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