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RECENT ADVANCES IN GASTRORETENTIVE FLOATING TABLETS: FORMULATION STRATEGIES, POLYMERIC APPROACHES AND IN-VITRO EVALUATION

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ABSTRACT

Gastroretentive floating tablets have emerged as an important pharmaceutical approach for prolonging gastric residence and achieving controlled release from oral solid dosage forms. Conventional tablets may undergo rapid and variable gastric emptying, which can limit the performance of formulations requiring prolonged exposure to the upper gastrointestinal environment. Floating tablets are designed to overcome this limitation by maintaining an apparent density lower than that of gastric contents, allowing them to remain buoyant for an extended period. Recent investigations have focused on improving floating performance through combinations of natural, semi-synthetic and synthetic polymers, advanced matrix-forming materials, optimized effervescent systems and novel manufacturing techniques. Natural polymers have received increasing attention because of their swelling characteristics, biodegradability and potential pharmaceutical applications, whereas cellulose derivatives and synthetic polymers continue to provide reliable control over matrix formation and release behaviour. This review presents an overview of

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gastroretentive floating tablets, emphasizing their principles, classification, formulation strategies, polymeric materials, manufacturing techniques and in-vitro evaluation parameters. Important formulation challenges, recent technological advancements and future research directions are also discussed. Particular attention is given to the relationship between floating lag time, total floating duration, swelling behaviour and matrix performance.

Keywords: Gastroretentive floating tablets; gastric retention; floating lag time; natural polymers; HPMC; polymeric matrix; buoyancy; swelling index; in-vitro evaluation.

1. INTRODUCTION

Oral solid dosage forms remain among the most widely used pharmaceutical preparations because of their convenience, manufacturing simplicity, stability and general acceptance among patients. Tablets are particularly important because they permit accurate unit dosing, efficient production, relatively economical packaging and considerable flexibility in formulation design. However, the performance of conventional oral tablets is influenced by physiological conditions within the gastrointestinal tract, including gastric motility, pH, fluid availability, food intake and gastrointestinal transit time. These factors may produce considerable variability in the residence of a dosage form within the stomach and consequently influence its release characteristics. In recent years, pharmaceutical researchers have increasingly investigated formulation technologies capable of improving the residence characteristics of oral solid preparations. Gastroretentive floating tablets represent one such approach, combining conventional tablet technology with physicochemical mechanisms that allow prolonged buoyancy in gastric fluid. The principle is based on reducing the apparent density of the dosage form so that it remains at the surface of gastric contents while gradually undergoing hydration, swelling and matrix erosion [1,2].

The development of gastroretentive floating tablets has attracted substantial attention because prolonged gastric residence can be advantageous for selected pharmaceutical applications. Unlike conventional tablets, which generally move through the gastrointestinal tract according to physiological emptying patterns, floating formulations are designed to resist immediate gastric evacuation through buoyancy. Their performance depends on a carefully established balance between the properties of the polymeric matrix, the generation or retention of gas, the physical characteristics of the tablet and the surrounding gastric environment. Recent studies have demonstrated that floating behaviour can be modified through polymer viscosity, matrix porosity, compression conditions and combinations of different excipients [3,4]. Advances in pharmaceutical materials have also encouraged the use of natural polysaccharides, modified cellulose derivatives and synthetic polymers capable of forming

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cohesive hydrated matrices. More recently, engineered porous structures and three-dimensional printing have provided additional opportunities to control tablet geometry and density [5,6].

2. CONCEPT OF GASTRORETENTIVE FLOATING TABLETS

Gastroretentive floating tablets are specially designed oral solid preparations that remain buoyant in gastric fluid because their apparent density is lower than that of the surrounding medium. Their principal objective is to prolong the residence of the formulation in the stomach while maintaining suitable physical and release characteristics. In conventional tablet formulations, gastric emptying may occur before the intended release period has been completed. Floating tablets attempt to address this limitation through the development of a low-density structure that remains at the surface of gastric contents. This mechanism generally involves polymer hydration, swelling, gas entrapment or incorporation of internal void spaces [2,7].

The floating concept is closely related to the physical principle of buoyancy. When the upward force exerted by the displaced gastric fluid exceeds the gravitational force acting on the tablet, the dosage form rises and remains buoyant. In practical pharmaceutical formulations, this condition can be achieved through gas generation or the use of materials and geometries that reduce apparent density. However, buoyancy alone does not determine the overall performance of a floating tablet. The formulation must also maintain adequate mechanical strength, resist premature disintegration and exhibit a reproducible hydration pattern [1,8,9].

3. PRINCIPLE AND MECHANISM OF FLOATING

The fundamental mechanism of a gastroretentive floating tablet involves the development and maintenance of an apparent density lower than that of gastric contents. In commonly used effervescent formulations, the tablet contains a hydrophilic polymer and a gas-generating agent, usually sodium bicarbonate. After contact with acidic gastric fluid, water penetrates the tablet and initiates polymer hydration. Simultaneously, sodium bicarbonate reacts with the acidic medium and produces carbon dioxide. The hydrated polymer forms a gel network capable of retaining the generated gas, which increases the internal volume and reduces the apparent density of the formulation [1,10].

The timing of polymer hydration and gas generation is particularly important. If carbon dioxide is generated before a sufficiently strong gel layer develops, gas may escape from the tablet, reducing its ability to float. Conversely, when the polymer hydrates effectively and forms a coherent matrix, gas bubbles remain entrapped and buoyancy can be maintained. The hydrated gel also influences the penetration of gastric fluid into the tablet and the movement of incorporated substances through the matrix. As hydration continues, the outer polymeric layer may gradually relax or erode, while the inner portion remains comparatively less hydrated [3,11].

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Two parameters are commonly used to describe floating behaviour. Floating lag time refers to the interval required for a tablet to rise to the surface of the test medium, whereas total floating time represents the duration for which it remains buoyant. Both parameters are influenced by polymer concentration, gas-generating agent, compression pressure, tablet porosity and the composition of the surrounding medium. A formulation with rapid initial buoyancy but poor structural stability may lose flotation prematurely, whereas a highly cohesive tablet may remain intact but exhibit an unnecessarily long floating lag time. Successful formulation therefore requires optimization of both characteristics [1,12].

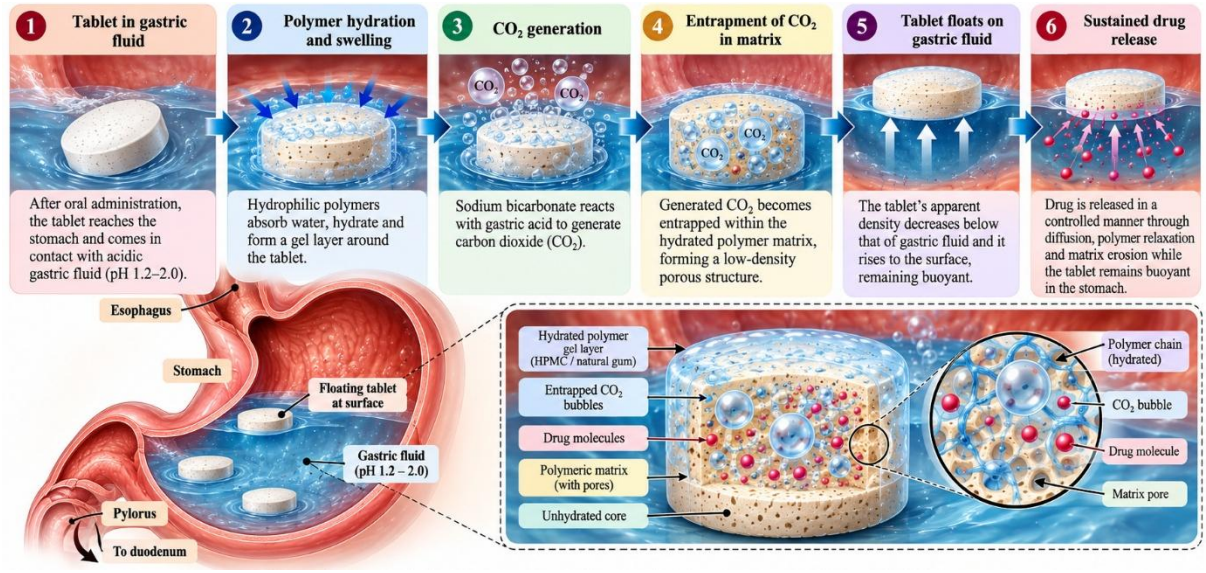

Figure 1. Mechanistic sequence of an effervescent gastroretentive floating matrix tablet.

4. CLASSIFICATION OF FLOATING TABLETS

Floating tablets are generally classified into effervescent and non-effervescent systems according to the mechanism responsible for buoyancy. Effervescent floating tablets contain gas-generating components that produce carbon dioxide following exposure to gastric fluid. Sodium bicarbonate is frequently incorporated either alone or in combination with organic acids such as citric acid or tartaric acid. The generated gas becomes trapped within a hydrated polymeric matrix, producing a low-density structure. This approach is widely investigated because it can be incorporated into conventional tablet manufacturing processes and permits adjustment of floating behaviour through changes in excipient concentration [1,4].

Non-effervescent floating tablets do not depend primarily on gas generation through an acid–base reaction. Instead, they employ swellable polymers, hydrocolloids, low-density materials or engineered internal structures. Upon contact with gastric fluid, the polymer hydrates and expands, forming a gel-like barrier that can retain

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air or maintain sufficient volume for buoyancy. Such systems may offer advantages where the performance of gas-generating agents is influenced by variations in gastric acidity. However, their success depends on the swelling characteristics, density and structural properties of the selected materials [5,8].

Floating formulations may also be classified according to their physical architecture. Conventional single-unit matrix tablets represent the simplest category, while more complex designs include bilayer tablets, porous tablets and floating devices manufactured through advanced processing techniques. Recent investigations have shown that specially engineered internal cavities can support buoyancy without requiring conventional effervescent components. These developments demonstrate the increasing importance of dosage-form architecture in floating tablet technology [6,13].

5. FORMULATION STRATEGIES FOR FLOATING TABLETS

Formulation development involves selecting suitable polymers, gas-generating agents and supporting excipients while establishing an appropriate manufacturing process. The formulation must possess adequate flow and compressibility before tablet formation and sufficient hardness, integrity and buoyancy after compression. These requirements are interconnected because changes introduced to improve one property may influence several others. For example, increasing polymer concentration can strengthen the hydrated matrix but may also modify water penetration and floating lag time. Similarly, increasing the amount of sodium bicarbonate may promote rapid buoyancy while changing tablet porosity and mechanical behaviour [3,10].

Direct compression is commonly preferred when the powder blend possesses satisfactory flow and compressibility. The method involves uniform blending of the formulation components followed by compression into tablets. Its advantages include manufacturing simplicity, fewer processing stages and avoidance of unnecessary exposure to heat or moisture. However, direct compression may be unsuitable when the selected powders exhibit poor flow, segregation or inadequate compactibility. In such circumstances, granulation techniques may be considered to improve processing characteristics [11,14].

Wet granulation involves preparing granules using a suitable binder solution before drying, sizing and compression. This method can improve powder cohesion and content uniformity, although exposure to moisture may influence the properties of some polymers and gas-generating agents. Dry granulation provides another alternative where moisture sensitivity is a concern. Regardless of the manufacturing method, process variables such as blending time, granule size, lubrication and compression force must be controlled to ensure reproducible tablet characteristics [4,15].

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6. ROLE OF POLYMERS IN FLOATING TABLET FORMULATION

Polymers are among the most important functional components of floating tablets because they influence hydration, swelling, gel formation, gas entrapment and structural stability. The choice of polymer determines how the tablet behaves after contact with gastric fluid and how effectively its low-density structure can be maintained. A suitable matrix-forming polymer should hydrate sufficiently to establish a coherent barrier while retaining adequate mechanical integrity during the intended floating period. Recent pharmaceutical research has examined natural, semi-synthetic and synthetic polymers, both individually and in combinations, to achieve improved formulation performance [1,5].

The viscosity of a polymer is particularly relevant because it influences the strength and thickness of the hydrated gel layer. High-viscosity polymers generally form stronger hydrated matrices, although excessive viscosity may delay water penetration or modify the rate of matrix erosion. Lower-viscosity polymers may hydrate more rapidly but can produce less resistant structures. Combining polymers with different hydration and viscosity characteristics may therefore provide a useful strategy for balancing rapid flotation with prolonged matrix integrity [1,16].

Polymer concentration also affects the density and internal structure of a floating tablet. Increasing the polymer proportion may improve gas entrapment and reduce premature disintegration, but excessive loading can increase tablet size and alter compression behaviour. Recent studies emphasize that polymer selection should be based on the required functionality rather than simply choosing the material with the highest viscosity or swelling capacity [5,16].

7. NATURAL POLYMERS USED IN FLOATING TABLETS

Natural polymers have gained increasing attention because of their availability, functional diversity and potential advantages in pharmaceutical formulation. Materials such as sodium alginate, xanthan gum, guar gum, pectin, chitosan and selected plant-derived gums have been investigated for their swelling, binding and gel-forming characteristics. These materials can contribute to matrix formation and may be combined with established pharmaceutical polymers to improve floating performance [5,17].

Sodium alginate is widely studied because it can form hydrated structures and gels under appropriate conditions. Its behaviour depends on molecular characteristics, ionic environment and formulation composition. Xanthan gum is another important polysaccharide because of its viscosity-enhancing and hydration properties. Recent investigations have examined chemical modification of xanthan gum to alter its functional characteristics and expand its suitability for gastroretentive formulations [17,18].

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Chitosan is particularly interesting because of its swelling and mucoadhesive properties. Its behaviour depends strongly on pH and degree of deacetylation, making material characterization important during formulation development. Guar gum and pectin have also been examined as matrix-forming and release-modifying excipients. Their usefulness depends on hydration behaviour, polymer concentration and compatibility with other formulation ingredients [5,19].

Despite their advantages, natural polymers may present difficulties related to batch variability, microbial quality, moisture sensitivity and differences in molecular composition. Therefore, their incorporation requires appropriate characterization and standardization. Natural origin alone does not guarantee superior pharmaceutical performance. Comparative studies are necessary to determine whether these materials provide reproducible advantages over conventional semi-synthetic or synthetic polymers [17,18].

8. SEMI-SYNTHETIC AND SYNTHETIC POLYMERS

Semi-synthetic polymers, particularly cellulose derivatives, continue to occupy an important position in floating tablet development. Hydroxypropyl methylcellulose (HPMC) is extensively used because it forms a hydrated gel layer after contact with aqueous fluid. This gel can retain gas bubbles and support matrix integrity. Different viscosity grades of HPMC provide flexibility in adjusting hydration, swelling and erosion characteristics. Hydroxyethyl cellulose and hydroxypropyl cellulose are also useful because of their water-absorbing and matrix-forming properties [1,16].

Synthetic polymers such as polyethylene oxide and carbomers provide additional opportunities for formulation modification. Polyethylene oxide is capable of substantial hydration and swelling, while carbomers can produce highly viscous hydrated networks. These characteristics may improve matrix cohesion when incorporated at appropriate concentrations. However, the performance of synthetic polymers depends on molecular weight, grade, concentration and interactions with other excipients [5,20].

Recent research increasingly emphasizes polymer combinations. Blending different polymers may allow the formulator to combine rapid hydration with adequate gel strength or modify matrix erosion without compromising buoyancy. Such combinations should be evaluated experimentally because polymer interactions may produce effects that cannot be predicted from the individual materials alone [1,20].

9. GAS-GENERATING AGENTS AND OTHER EXCIPIENTS

Gas-generating agents play a central role in effervescent floating tablets. Sodium bicarbonate is commonly used because it produces carbon dioxide following exposure to acidic gastric fluid. The generated gas becomes entrapped within the hydrated matrix and reduces apparent tablet density. Citric acid and tartaric acid may be

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included to support gas generation, although their concentration must be optimized to prevent excessive porosity or premature matrix disruption [3,10].

Diluents are incorporated to obtain suitable tablet weight and improve compression characteristics. Microcrystalline cellulose, lactose and other pharmaceutically acceptable fillers may be selected according to formulation requirements. Binders improve powder cohesion, whereas lubricants and glidants facilitate manufacturing. Although these excipients may be present in comparatively small quantities, their influence on wettability, density, porosity and mechanical strength can be significant [11,14].

10. FACTORS AFFECTING FLOATING BEHAVIOUR

Floating behaviour is influenced by several formulation and physiological factors. Polymer viscosity and concentration affect the rate of hydration and the strength of the gel network. Gas-generating agent concentration influences the quantity and rate of carbon dioxide formation. Tablet hardness and porosity determine how quickly gastric fluid penetrates the matrix, while tablet geometry influences surface area and the development of buoyancy [3,16].

Compression pressure is particularly important because excessive compression can reduce porosity and delay fluid penetration. Conversely, insufficient compression may produce tablets with inadequate mechanical strength. The surrounding medium also influences performance through its pH, volume and agitation conditions. Therefore, floating characteristics obtained under one experimental condition may differ when the same formulation is evaluated under another [2,12].

11. PRE-COMPRESSION EVALUATION

Pre-compression evaluation is performed to determine whether the powder blend possesses suitable properties for tablet manufacture. Bulk density represents the mass of powder divided by its untapped bulk volume, whereas tapped density is determined after controlled tapping. These measurements provide information about packing behaviour and are used to calculate Carr's compressibility index and Hausner ratio [11,14].

Carr's index is calculated as:

Carr's Index (%) = [(Tapped Density − Bulk Density) / Tapped Density] × 100

Hausner ratio is expressed as:

Hausner Ratio = Tapped Density / Bulk Density

The angle of repose provides an additional indication of powder flow behaviour. These measurements are useful during formulation development, although they should be interpreted collectively because no single parameter completely describes powder flow under manufacturing conditions. Appropriate pre-compression characteristics contribute to

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uniform die filling, reproducible tablet weight and satisfactory compression performance [11].

12. POST-COMPRESSION EVALUATION

Post-compression evaluation establishes whether prepared tablets possess acceptable physical characteristics. Weight variation testing examines consistency of tablet mass, while thickness measurements provide information about dimensional uniformity. Hardness testing evaluates resistance to mechanical breakage, and friability testing determines the tendency of tablets to lose mass during controlled mechanical agitation [14,19].

These parameters are particularly relevant for floating formulations because tablet integrity must be maintained during handling and exposure to gastric fluid. Excessive hardness may delay hydration, whereas inadequate hardness can produce premature fragmentation. Friability should therefore be evaluated alongside buoyancy and swelling rather than independently [11,19].

13. IN-VITRO BUOYANCY AND SWELLING STUDIES

In-vitro buoyancy testing is one of the defining evaluations for gastroretentive floating tablets. The formulation is introduced into an appropriate simulated gastric medium maintained under controlled conditions. The time required for the tablet to rise is recorded as floating lag time, while the duration of buoyancy is recorded as total floating time. These parameters allow comparison of different formulations and provide information about the effectiveness of polymer hydration and gas entrapment [1,12].

Swelling studies are performed to examine water uptake and changes in tablet mass or dimensions. The swelling index may be calculated as:

Swelling Index (%) = [(Wt − W0) / W0] × 100

where **Wt** represents the weight of the swollen tablet at a specified time and **W0** represents its initial weight.

Swelling behaviour provides useful information about the formation and development of the hydrated polymeric matrix. However, excessive swelling may compromise structural integrity, while insufficient swelling may limit gas entrapment. The objective is therefore to obtain controlled hydration that supports prolonged buoyancy without causing premature matrix failure [16,20].

14. IN-VITRO DISSOLUTION AND RELEASE KINETICS

In-vitro dissolution testing is used to characterize the release behaviour of floating matrix tablets under defined experimental conditions. The test medium, apparatus, agitation speed, temperature and sampling intervals should be selected according to the formulation objective and an appropriately justified analytical method. Dissolution profiles provide information about the influence of polymer concentration, matrix structure and formulation composition on release behaviour [3,15].

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Mathematical models are frequently used to describe dissolution data. The zero-order model represents release at a constant rate, whereas the first-order model describes release dependent on the remaining amount. The Higuchi model is associated with diffusion-controlled release under its underlying assumptions, while the Korsmeyer–Peppas model is commonly used to investigate the contribution of different release mechanisms [15].

15. RECENT ADVANCES IN FLOATING TABLET FORMULATION (2020–2026)

Recent developments in floating tablet technology have focused on improving formulation reliability through advanced polymer combinations, modified matrix structures and innovative manufacturing techniques. Research published during 2020–2022 emphasized the relationship between polymer viscosity, hydration, swelling and buoyancy, with particular attention to low-density matrices and the influence of formulation variables. Investigations also demonstrated the potential of combining swelling and floating mechanisms to improve tablet performance [7,20,21].

Between 2022 and 2024, three-dimensional printing emerged as an increasingly important manufacturing strategy. Fused deposition modelling permitted the production of tablets containing internal void spaces, enabling buoyancy through geometrical design rather than relying exclusively on effervescent reactions. Oladeji and colleagues demonstrated that appropriately designed printed tablets could exhibit immediate buoyancy, while subsequent research explored the influence of polymer composition and internal structure on floating and release behaviour [6,22].

Research published during 2024–2025 further expanded these approaches through advanced polymers, porous cellulose-based matrices and engineered floating devices. Porous structures prepared through templating methods demonstrated that controlled internal architecture can influence buoyancy and matrix characteristics. Similarly, partially coated printed systems illustrated how the combination of polymer properties and geometric design could provide prolonged floating behaviour [5,23,25].

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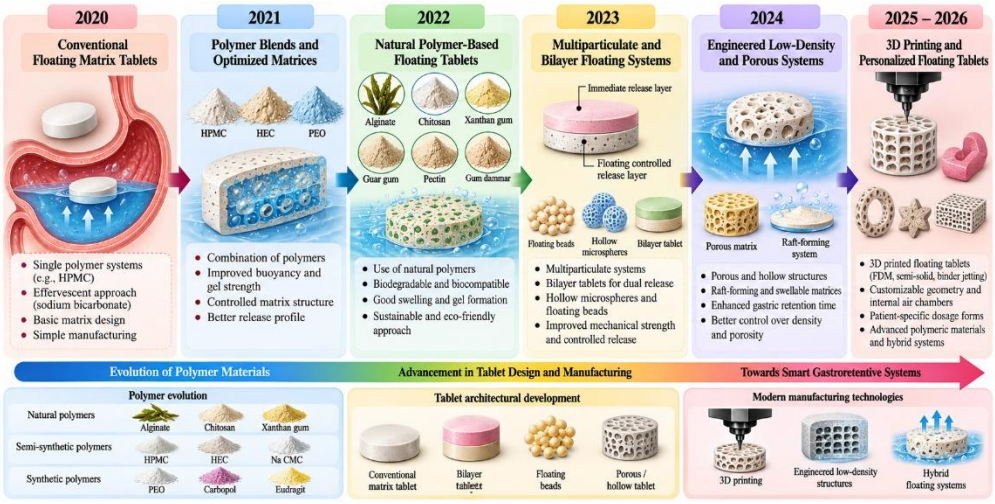

Figure 2. Evolution of polymeric and technological strategies for gastroretentive floating tablets.

16. CHALLENGES AND LIMITATIONS

Despite considerable progress, floating tablet development continues to face several challenges. One major limitation is the difficulty of translating laboratory buoyancy into predictable gastric residence. Simulated gastric media cannot completely reproduce the complexity of human gastric conditions, particularly variations in motility, food intake and fluid availability. Therefore, prolonged in-vitro flotation should not be interpreted as definitive evidence of prolonged in-vivo retention [2,9].

Manufacturing reproducibility is also important, especially when natural polymers or complex tablet architectures are used. Variability in polymer properties, compression conditions and excipient distribution may affect performance. Advanced manufacturing technologies offer new possibilities but introduce additional requirements relating to material compatibility, processing validation and scale-up [5,6].

17. FUTURE PERSPECTIVES

Future development of gastroretentive floating tablets is likely to emphasize greater control over polymer properties, matrix geometry and formulation reproducibility. Natural polymer modification may provide opportunities to improve swelling, hydration and gel formation, while combinations of established polymers may offer a practical means of balancing buoyancy and mechanical integrity. Systematic experimental design and statistical optimization will remain valuable for identifying interactions among formulation variables [6,23].

18. CONCLUSION

Gastroretentive floating tablets represent an important approach for improving the residence characteristics of oral solid dosage forms. Their performance depends on the combined influence of polymer hydration, swelling, gas generation, tablet density, mechanical strength and formulation architecture. Natural, semi-synthetic

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and synthetic polymers each offer useful characteristics, and their appropriate selection remains central to successful formulation development. Recent advances have expanded conventional floating tablet technology through polymer blends, porous structures, hybrid systems and three-dimensional printing. Nevertheless, reliable in-vitro evaluation and systematic optimization remain essential because improved buoyancy does not automatically guarantee prolonged gastric residence under physiological conditions. Future developments are expected to focus on reproducible polymeric matrices, innovative manufacturing techniques and more physiologically relevant testing methods.

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