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Review Article

Floating Drug Delivery Systems: Mechanisms, Formulation Approaches, and Future Prospects

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ABSTRACT

Floating Drug Delivery Systems (FDDS) is an efficient gastroretentive drug delivery system designed to address the shortcomings associated with traditional oral drug delivery systems. The system uses effervescent or non-effervescent techniques to ensure that it stays buoyant in the stomach due to its density being lower than that of gastric fluid. The technique is also known to improve bioavailability for drugs that have low half- life or specific gastric targets. This review paper explains the mechanism and process associated with FDDS. In this context, various types of drug delivery systems like tablets, capsules, microspheres, beads, and raft tablets have been explained. Nonetheless, some of the latest developments in FDDS include microspheres, nanotechnology-based drug delivery systems, smart polymers, dual mechanism drug delivery system, and 3D printing technology. The presented study provides insights into the efficiency and potential associated with FDDS in oral drug delivery.

INTRODUCTION

People generally find taking medication orally very convenient and painless. Sometimes, the medication moves too quickly through the stomach and the small intestines, giving the body insufficient time to process and absorb it.(1) To counter this, a special drug delivery system named Gastroretentive Drug Delivery Systems (GRDDS) was developed. Gastro-Retentive Drug Delivery System (GRDDS) is a novel oral drug delivery system with a target of maximizing the dwell-time of a dosage form in the stomach region. In standard oral drug delivery systems, dosage forms move quickly through the GI tract, which may cause suboptimal release of the drug or decreased bioavailability, especially for a drug which has a preference for absorption in the stomach or the upper part of the small intestine. [2] GRDDS overcomes these limitations by retaining the drug delivery system in the gastric region for an extended period, thereby ensuring controlled and

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site-specific drug release. This system is particularly beneficial for drugs that:

Have a narrow absorption window in the upper GI tract

Are locally active in the stomach (e.g., drugs for gastric ulcers or Helicobacter pylori infection)

Are unstable or poorly soluble at intestinal pH

Require prolonged therapeutic action(3,4)

Advantages of Gastro-retentive Drug Delivery System (GRDDS)

i. **Improved Bioavailability:** Prolonged gastric residence time increases the bioavailability of drugs that depend on the stomach or the proximal part of the small intestine for absorption.
ii. **Sustained Drug Delivery / Minimized Frequency of Dosing:** GRDDS allows controlled and prolonged drug release, thereby reducing dosing frequency and improving patient compliance.
iii. **Minimal Fluctuation of Drug Concentration:** The continuous release of the drug maintains steady plasma levels of the drug and minimizes peak–trough fluctuations.
iv. **Reduced Adverse Activity in the Colon:** By limiting drug exposure to the colon, GRDDS reduces colonic irritation and side effects associated with unstable drugs or irritating drugs in the lower GI tract.(5,6)
v. **Enhanced therapeutic efficacy:** Prolonged drug release at the absorption site improves therapeutic effectiveness, especially for drugs with a short half-life.
vi. **Better Patient Compliance:** Less frequent dosing and consistent therapeutic effect result in better adherence to treatment regimens.
vii. **Site-Specific Drug Delivery in the Stomach:** GRDDS are ideal for drugs intended for local action in the stomach, such as antacids, antibiotics for Helicobacter pylori, and anti-ulcer drugs.Reduced Drug Wastage: Controlled and targeted drug release minimizes drug loss due to premature passage through the gastrointestinal tract.viii. Better Absorption of Drugs with Narrow Absorption Window: Drugs that exhibit absorption only in the upper GI tract are greatly benefited by extended gastric retention.
viii. **Reduced Dose Requirement:** Because of the improved bioavailability, the total drug dose can be reduced to avoid dose-related toxicity.(7)
ix. **Improved Solubility of Weakly Basic Drugs:** The acidic environment in the stomach enhances the dissolution of weakly basic drugs, thereby promoting their absorption.
x. **Suitable for Drugs Degraded in Intestinal pH:** GRDDS protects drugs that are unstable in the alkaline environment of the intestine by retaining them in the stomach.(8)

Types of the gastroretentive system

Gastro-retentive drug delivery systems are designed using different formulation approaches to prolong the residence time of dosage forms in the stomach. Based on the mechanism by which gastric retention is achieved, the GRDDS can be classified into following major types:

i. **Floating Drug Delivery Systems:** The density of these systems is less than that of gastric fluid; thus, these systems can float on the stomach contents for a considerable period of time. The drug is released while the

system is buoyant, making it suitable for drugs whose absorption takes place in the upper GI tract.(9)

ii. **High-Density Systems:** These are formulated with materials having a density greater than that of gastric fluid. They sink to the bottom of the stomach and resist peristaltic movements, thus increasing gastric retention time.

iii. **Swelling and Expanding Systems:** These are systems that swell or expand rapidly following contact with gastric fluid to a size that is large enough to prevent passage through the pylorus. This allows for prolonged gastric residence, thereby providing a sustained drug release.iv. Bioadhesive systems: These systems adhere to the gastric mucosal surface because of bioadhesive polymers, resisting gastric emptying and improving drug absorption.(10,11,12)

iv. **Raft-Forming Systems:** Raft-forming systems form viscous, gel-like floating rafts in the presence of gastric fluid. They are particularly useful in the treatment of gastric reflux and ulcer conditions.

v. **Carbon dioxide gas-generating systems:** Upon their contact and reaction with gastric acid, a sufficient amount of carbon dioxide gas is produced; this gas gets entrapped in the dosage form, thereby reducing its density and allowing it to float.

vi. **Ion-exchange resin systems:** Drugs complexed with ion-exchange resins are slowly released in the acidic gastric environment, resulting in prolonged gastric retention and sustained release of the drug. Hydrodynamically Balanced Systems (HBS): These are single-unit floating systems formulated with hydrophilic polymers that swell and maintain buoyancy in gastric fluid, ensuring sustained drug delivery.(13,14)

Figure 1: Types of Gastro-retentive drug delivery systems

Of the different approaches for GRDDS, FDDS is the most promising and widely investigated approach. This is because floating systems are designed such that their density is lower than that of the gastric fluid, enabling them to float on the stomach for an extended period of time without interfering with normal gastric emptying. The drug is released in a controlled manner at the desired site while floating on the gastric contents.

The reasons that floating systems represent the most promising GRDDS approach include:

i. **Simplicity of Design and Formulation** Floating systems can be formulated using conventional polymers and excipients; hence they are more practical and cost-effective compared to complex expandable or bioadhesive systems.(15)
ii. **Prolonged Gastric Residence Time:** Since the floating systems maintain buoyancy, they can stay in the stomach for many hours, allowing extended drug release and enhancement of therapeutic efficacy.(16)
iii. **Better Patient Compliance:** Floating dosage forms are generally well tolerated and do not cause any gastric irritation or obstruction, unlike some swelling or expandable systems.
iv. **Wide Applicability:** Floating systems are suitable for many drugs, especially those that are absorbed in the stomach or upper small intestine, have a narrow absorption window, or are unstable at intestinal pH.(17, 18)
v. **Reduced Risk of Gastric Obstruction:** Unlike expandable systems, floating systems do not depend on heavy swelling to achieve retention, hence diminishing risks for gastric blockage.
vi. **Steady-state and controlled drug delivery:** floating systems can keep steady plasma drug concentrations by providing sustained drug release while remaining in the gastric region.
vii. **Clinical and commercial success:** Various floating formulations have reached clinical development and commercialization, thus exhibiting practical feasibility and regulatory acceptance.(19)

FDDS basically stand for Floating Drug Delivery Systems, a specialized gastro-retentive drug delivery system. This is designed to stay afloat in the stomach for an extended time. These systems exhibit less density compared to that of gastric fluid, thus these can float on the gastric contents and may not impede the normal process of gastric emptying. The floating may cause the release of the drug in a controlled and sustained manner, allowing prolonged therapeutic action. The prolonged gastric residence time of FDDS increases absorption, mainly of those drugs that are preferentially absorbed from the stomach or the upper part of the small intestine. This approach highly improves bioavailability, therapeutic efficacy, and patient compliance.(20)

Principle of Floating Drug Delivery Systems

FDDS works based on the principle of buoyancy.FDDS is based on the principle of buoyancy. When this dosage form comes in contact with gastric fluids, it is too:

- Producing gas which accumulates in the system and reduces its density, or
- Swell to form a low-density, gel-like consistency that will float.

This leads to a dosage form remaining in the stomach for a couple of hours and releasing the drug at a desired site.(21,22,23)

Suitability Of Floating Drug Delivery Systems

Floating Drug Delivery Systems are specifically beneficial in:

- Drugs absorbed primarily from the upper GI tract, including the stomach and the upper parts of the small intestine
- Drugs that lack good solubility or stability in intestinal fluids
- Drugs with a short biological half-life, which need frequent administration
- Drugs for topical administration within the stomach, for instance, antulcer medications and antacids

By holding the dosage form in the stomach, FDDS helps increase the absorption of the drug and reduce the loss of the drug by rapid gastric emptying.

Benefits of Floating Drug Delivery Systems

- **Prolonged Gastric Residence Time:** The floating tablets or capsules are retained in the gastric phase for an extended period, thus ensuring a prolonged drug release.
- **Increased Drug Absorption and Bioavailability:** FDDS increase the absorption of drugs, which are better absorbed under acidic pH or in the upper gastrointestinal region.
- **Decreased Dosage Intervals:** The need for frequent dosing is reduced due to sustained drug releases.
- **Minimized Side Effects:** The controlled release of the drug helps to minimize the peak level of the drug in the plasma and thereby the side effects of the drug.
- **Effective in Diarrhea and Gastric Motility:** In cases of diarrhea and increased gastric motility, FDDS may preserve the retention of the drug in the gastrointestinal tract.
- **Increased Patient Compliance:** Lower doses of the drug and higher effectiveness of therapy reduce the chances of patient noncompliance.
- **Suitable for Local Gastric Action:** FDDS are best suited for catering to medications which are designed for local action in the stomach, for example, antibiotics and anti-ulcer medications.(23)

Factors Affecting the Floating and Floating Time of FDDS

The factors affecting floating and floating time of FDDS are as follows: The performance of FDDS largely depends on their ability to remain buoyant in the gastric fluid and retain a position in the stomach for a longer period. Several physiological, formulation-related, and patient-specific factors influence the floating behavior and gastric retention time.

- **Density of the Dosage Form:** The most critical factor affecting floating behavior is the density of the dosage form. For effective floating, the density of the system should be lower compared to that of the gastric fluid (approximately 1.004 g/cm³). Dosage forms of lower density remain buoyant for a longer time, while systems of higher density tend to sink and are rapidly emptied from the stomach.
- **Dosage Form Shape:** The shape of the dosage form significantly affects gastric retention and floating stability. It has been observed that tetrahedral and ring-shaped dosage forms possess more excellent floating behaviour and longer gastric residence time as compared to spherical or flat shapes since they can better resist peristaltic movements of the stomach.

Size of Dosage Form: The size of the dosage form is also very significant in determining gastric retention. Dosage forms that are larger than 9.5mm in size will tend to reside in the stomach for a relatively longer time, whereas smaller dosage forms will readily pass into the intestines due to the pyloric sphincter during gastric emptying.(24)

- Gender, Posture, and Age: Various physical properties such as gender, posture, and age

demonstrate the effects on gastric emptying time.

- Gastric emptying is slower in females than in males.
- The elderly, especially those above 70 years old, tend to have slow gastric emptying.
- Body position, whether erect or supine, might influence gastric contractions and the flotation process.
- Effect of Concomitant Drugs: Some drugs can cause a change in gastric motility, which can have a subsequent effect on the
- Atropine, glycopyrrolate, metoclopramide, and domperidone can
- But then again, medications such as neostigmine may cause the slowing down of gastric motility, resulting in the prolongation of gastric retention for the floating system.

Disease State: There are numerous diseases that may adversely influence gastric emptying:

- Diabetes mellitus and Crohn's disease could affect gastric motility and emptying.
- There is a relation of depression to delayed gastric emptying.
- Certain conditions such as stress or anxiety may contribute to faster gastric emptying by increasing gastric motility. Stress and anxiety can also cause faster gastric emptying(25)

Types of floating Drug Delivery System

There are different types of floating systems depending on the floating mechanism:

1. Effervescent (Gas-Generating)

Effervescent-floating systems produce buoyancy by the production of carbon dioxide gas when they come into contact with gastric fluid. The produced gas gets entrapped in the polymer matrix, causing the density of the dosage form to decrease and resulting in the production of a floating system.

Effervescent Floating System Composition Such systems always comprise:

- Gas-producing substances: Sodium bicarbonate, Calcium carbonate
- Acidic parts: Citric acid or tartaric acid (optional, for the purpose of gas evolution
- Hydrophilic polymers: HPMC, Carbopol,
- Excipients: Binders, Lub

Table No. 1: Types of Effervescent (Gas-Generating) Floating Drug Delivery Systems(22,23,24,25,26)

Type of Effervescent System	Dosage Form	Composition / Key Components	Mechanism of Floating	Advantages	Limitations
Floating Tablets	Tablets	Hydrophilic polymers (HPMC), gas-generating agents (sodium bicarbonate, citric/tartaric acid)	CO_2 generated in an acidic medium gets trapped in a swollen polymer matrix, reducing density	Simple formulation, prolonged floating time, controlled drug release	It depends on gastric acidity, the floating lag time
Floating Capsules	Capsules	Effervescent granules or powders with polymers and	CO_2 generation causes buoyancy after	Easy to manufacture, flexible dose loading	Variable floating time, less mechanical strength

		gas-forming agents	the capsule shell dissolves		
Floating Granules / Pellets	Granules pellets	Drug, polymer, sodium bicarbonate, organic acids	Gas generation lowers the density of individual units	Uniform drug release, reduced dose dumping	More complex manufacturing
Floating Beads	Beads	Alginate or polymer matrix with gas-forming agents	CO_2 entrapped within the bead structure	Multiple-unit system, improved gastric retention	Limited drug loading capacity
Effervescent Microspheres	Hollow microspheres	Polymer shell (e.g., ethyl cellulose), gas-forming agents	Hollow core formed by CO_2 generation provides buoyancy	Prolonged floating, controlled release, reduced irritation	Expensive and technically demanding
Raft-Forming Effervescent Systems	Liquid/gel systems	Sodium alginate, bicarbonates, calcium salts	Formation of a floating gel raft due to CO_2 generation	Excellent for GERD, localized gastric action	Not suitable for systemic drug delivery

Mechanism of Effervescent (Gas-Generating) Floating Drug Delivery Systems (FDDS):

a) **Effervescent or gas-producing :** floating systems are designed to generate gas in response to the gastric fluid to which the dosage form is exposed. The gas helps reduce the density of the drug, which then allows it to float along with the gastric fluids in the stomach for an extended period, thus releasing the drug in a regulated fashion.

b) **Hydration and Polymer Swelling:** The hydrophilic polymers in the formulation start to swell by absorbing the gastric fluid, creating a kind of barrier around the dosage form due to the formation of a gel-like structure.

c) **Effervescent Reaction (Gas Generation):** The gas-generating reagent (for example, sodium bicarbonate) reacts with gastric acid (or organic acids), resulting in the evolution of carbon dioxide gas according to the following reaction:

d) **Gas Entrapment in a Polymer Matrix:** The produced CO_2 is trapped in the swelled polymeric matrix, leading to an expansion in the dosage form and a reduction in its density.

e) **Buoyancy and Floating Phenomena:** With a density difference in favor of gastric fluids (approximating 1.004 g/cm³), the drug particles float on top of the gastric liquor.

f) **Prolonged Gastric Retention:** The final property of floating is its role in prolonging gastric

g) **Controlled Drug Release:** While floating, the drug is released gradually through diffusion and/or erosion of the polymer

matrix, maintaining sustained plasma drug levels.(27,28)

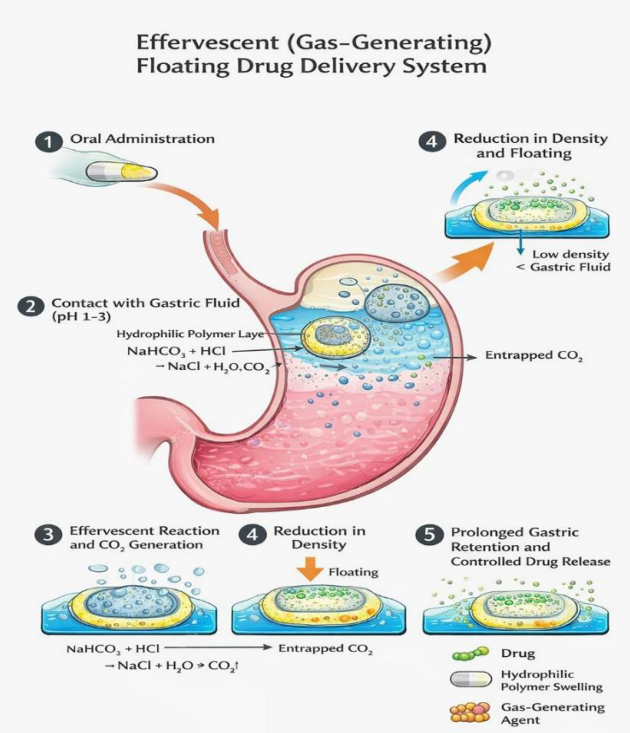

Figure 2: Mechanism of Effervescent (Gas-Generating) Floating Drug Delivery Systems

2.Non-Effervescent Floating Systems

Non-effervescent floating systems are a form of gastro-retentive drug delivery systems (GRDDS). These systems work by being buoyant without the production of gas. The primary function of non-effervescent floating systems is carried out by swellable and gelation polymers such as hydroxypropyl methylcellulose (HPMC).

In contrast to effervescent systems, non-effervescent systems do not include gas-releasing agents but rely on the hydration and gelation processes of polymers for lightness and floatation.

Principle of Non-Effervescent Floating Systems

The principle on which non-effervescent floating systems lie is that of hydrodynamic balance. When the dosage form is exposed to gastric fluid:

- hydrophilic polymers: Quickly hydrate and
- A gel barrier is formed around the drug formulation
- The swollen system has a bulk density below that of gastric fluid
- The dosage form remains Buoyant for an Extended Period
- Drug is delivered in a controlled and sustained fashion(29,30)

Table No. 2: Types of Non-Effervescent Floating Drug Delivery Systems(28,29,30,31)

Type	Dosage Form / System	Key Components	Mechanism of Floating	Major Advantages	Applications

Hydrodynamically Balanced Systems (HBS)	Tablets / Capsules	Hydrophilic polymers (HPMC, Carbopol), drug	Polymer hydrates and forms gel; density remains lower than gastric fluid	Prolonged gastric retention, controlled drug release	Drugs absorbed in the stomach or upper intestine
Floating Tablets and Capsules	Single-unit dosage forms	Swelling polymers (HPMC, sodium alginate), drug	Polymer swelling creates a low-density gel matrix	Simple formulation, sustained drug release	Short half-life drugs, gastric-specific delivery
Floating Microspheres (Microballoons)	Hollow microspheres	Polymers (ethyl cellulose, Eudragit), drug	Hollow core provides buoyancy	Uniform drug release, reduced dose dumping	Long-term gastric retention, chronic therapy
Floating Alginate Beads	Beads	Sodium alginate, calcium chloride, and the drug	Swelling and air entrapment in gel matrix	Good mechanical strength, sustained release	Local gastric action, controlled delivery

Mechanism of Action

- **Oral Dosage:** The non-effervescent floating tablet or capsule is taken orally.
- **Contact with Gastric Fluid:** On arrival at the stomach, the drug form comes into contact with the gastric fluid.
- **Polymer Hydration:** The hydrophilic polymer Hydroxyzine absorbs gastric fluids and hydrates.
- **Swelling and Gelation:** The polymer absorbs water to form a viscous hydrogel enveloping the drug product.
- **Buoyancy Achievement:** The buoyant system has a density that is less than that of gastric fluid; therefore, it floats.
- **Prolonged Gastric Retention:** The floating drug reduces the risk of rapid gastric emptying
- **Controlled Drug Release:** The release of the drug is achieved slowly through the process of diffusion and erosion of the gel layer.(32,33)

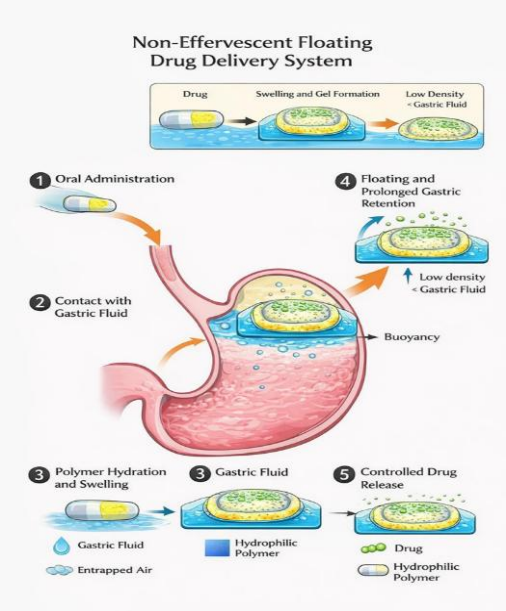

Figure 3: Mechanism of Non-Effervescent Floating Drug Delivery Systems

Polymer used for a floating drug delivery system

Polymers are also important constituents in the design and development of Floating Drug Delivery Systems (FDDS). These polymers are mainly responsible for providing buoyancy, drug release, and the strength of the drug delivery system in the gastric environment. However, the choice of the appropriate polymer is contingent on factors such as swelling properties, gelation capacity, density, viscosity, and drug compatibility. In FDDS, the polymers absorb the gastric fluid and increase in size to form a thick gel layer around the drug delivery system, making it float as well as preventing the release of the drug quickly. Certain polymers are also responsible for gas entrapment in effervescent systems or for maintaining the entrapped air in non- effervescent systems, thus decreasing the overall system density. In FDDS, the polymers can be either natural, semi-synthetic, or synthetic in nature. (34)Natural polymers like sodium alginate, guar gum, or chitosan are more desirable due to their biocompatible and biodegradable properties. Amongst the semi-synthetic polymers, derivatives such as cellulose are more desirable as hydroxypropyl methylcellulose (HPMC) because of its optimal swelling and drug release capacity. Other synthetic polymers such as Eudragit, polyvinyl alcohol, or biodegradable polymers like PLGA, are used to provide exact drug release along with precise control over drug release and mechanical strength.(35,36)

Table No. 3: Polymers used for a floating drug delivery system (36,37)

Category	Polymer Name	Type	Role in FDDS	Uses
	Sodium alginate	Seaweed-derived polysaccharide	Swelling, gel formation, buoyancy	Widely used in floating beads and raft-forming systems
	Pectin	Plant polysaccharide	Gel formation, controlled release	Used in gastric- retentive formulations

Natural Polymers	Chitosan	Deacetylated chitin	Swelling, mucoadhesion	Enhances gastric retention and bioadhesion
	Guar gum	Plant-derived galactomannan	Swelling, viscosity enhancement	Used in sustained release floating tablets
	Xanthan gum	Microbial polysaccharide	Gel formation, viscosity control	Improves matrix integrity
	Carrageenan	Red seaweed polysaccharide	Gel formation	Used in floating matrices
Semi-Synthetic Polymers	Hydroxypropyl methylcellulose (HPMC)	Cellulose derivative	Swelling, gel formation, floating	Most commonly used polymer in FDDS
	Hydroxyethyl cellulose (HEC)	Cellulose derivative	Matrix formation, sustained release	Improves tablet integrity
	Hydroxypropyl cellulose (HPC)	Cellulose derivative	Swelling, controlled release	Used in hydrodynamically balanced systems
	Sodium carboxymethyl cellulose (NaCMC)	Cellulose derivative	Swelling, viscosity enhancement	Used in floating tablets
	Ethyl cellulose	Cellulose derivative	Release retardant, matrix former	Used in microspheres and microballoons
Synthetic Polymers	Eudragit® (RL, RS, NE)	Methacrylate polymers	Matrix formation, controlled release	Widely used in floating microspheres
	Polyvinyl alcohol (PVA)	Synthetic polymer	Film formation, matrix stability	Used in microballoons
	Polyethylene oxide (PEO)	Synthetic polymer	Swelling, gel formation	High swelling capacity
	Polyvinylpyrrolidone (PVP)	Synthetic polymer	Binder, release modifier	Improves tablet strength
	Polylactic acid (PLA)	Biodegradable polymer	Matrix formation	Used in floating microspheres
	Polylactic-co-glycolic acid (PLGA)	Biodegradable copolymer	Controlled drug release	Used in advanced gastroretentive systems

Characterization of Floating Drug Delivery Systems (FDDS)

Characterization of Floating Drug Delivery Systems (FDDS) is essential to ensure adequate

buoyancy, prolonged gastric retention, controlled drug release, and formulation stability. Evaluation of FDDS involves the assessment of floating behavior, swelling characteristics, drug content uniformity, and drug release profile. These studies help in predicting the in vivo performance of the system and confirm its suitability for gastro-retentive drug delivery. The various characterization parameters of FDDS are summarized in the table(38)

Table No.4: Characterization of Floating Drug Delivery Systems (FDDS)

Parameter	Test / Method	Short Write-up (Purpose & Significance)
Floating Lag Time (FLT)	In vitro buoyancy test in simulated gastric fluid (0.1 N HCl)	Time taken by the dosage form to rise to the surface. Short FLT indicates a rapid onset of floating.
Total Floating Time (TFT)	In vitro buoyancy study	Duration for which the dosage form remains floating. Indicates gastric retention capability.
In vitro Buoyancy	Observation in dissolution medium	Confirms the floating behavior and stability of the system in gastric conditions.
Swelling Index	Weight gain method	Measures the extent of polymer swelling, which influences buoyancy and drug release.
Drug Content Uniformity	Assay using UV/ HPLC	Ensures uniform distribution of the drug in the formulation for dose accuracy.
In vitro Drug Release	USP dissolution apparatus (Type I or II)	Determines the rate and pattern of drug release from the floating system.
Release Kinetics	Mathematical models (Zero order, Higuchi, Korsmeyer–Peppas)	Explains the mechanism of drug release (diffusion, erosion, or both).
Tablet Hardness	Monsanto or Pfizer hardness tester	Ensures mechanical strength and resistance to handling stress.
Friability	Roche friabilator	Measures tablet resistance to abrasion; acceptable limit is usually <1%.
Thickness and Diameter	Vernier caliper	Ensures uniformity in tablet dimensions.
Weight Variation	Pharmacopoeial method	Confirms uniformity of dosage units.
Density Measurement	Volume and weight determination	Density must be lower than gastric fluid for effective floating.
Surface Morphology	Scanning Electron Microscopy (SEM)	Examine surface characteristics, porosity, and polymer structure.
Stability Studies	ICH guidelines (accelerated conditions)	Evaluates physical and chemical stability over time.
In vivo Gastric Retention (optional)	X-ray or gamma scintigraphy	Confirms gastric residence timeunder physiological conditions.

Recent Advancements in Floating Drug Delivery Systems (FDDS)

Floating Drug Delivery Systems (FDDS) have been recognized and identified as one of the most

promising areas in gastro retentive drug delivery systems for improving oral bioavailability of drugs with a narrow absorption window, short half-life, and/or preferring stomach and upper GI tract for absorption. Although conventional FDDS have offered a wide range of applications with many advantages, contemporary pharmaceutical research has concentrated on addressing drawbacks, including dependence on gastric emptying patterns, gastric pH, and difficulty in controlling drug release in conventional FDDS. Consequently, new approaches have been introduced to optimize FDDS and make it more efficient and successful.

The progress of FDDS is motivated by:

- unpredictable gastric retention because of physiological variations
- Short duration of floating in conventional systems
- Performance in fasted state scenarios
- Need for better control over drug release kinetics
- Patient-friendly drug delivery systems that target specific needs.

Such challenges have motivated the emergence of the next-next-generation solar floaters with enhanced efficiency and reproducing abilities.(39)

- **Advanced Polymer-Based Floating Systems**

Current studies also highlight the application of new and multi-functioning polymers for enhanced buoyancy and drug release.

Major Break-Through

- High-viscosity and blend polymers (such as combinations of HPMC and natural gums) to enhance the strength of gels
- Stimuli-sensitive polymers that are sensitive to either pH, ion strength, or gastric motility.
- Combination of bioadhesive polymers and floating polymers to enhance dual gastro-retention properties.

Benefits

- Improved floating stability
- Longer gastric residence time
- Enhanced drug release predictability
- Floating Microspheres & Micro

One of the most important developments in FDDS is the creation of microballoons, or floating microspheres.

Key Features

The

- Hollow spherical structures with low density
- By solvent diffusion or emulsion methods
- Offer advantages over multiple-unit dosage forms

Advantages

- Lower risk of dose dumping
- Uniform distribution in stomach
- Increased patient safety and adherence

It would seem that drug delivery systems are most beneficial for use in chronic therapy, where a drug needs to release slowly for

i. Raft-Forming Advanced Systems

Raft forming systems today embody an evolved form of conventional floating systems. Innovations

- Enhanced alginate raft systems with better mechanical strength

- Calcium release agents for rapid gelation
- Improved floating lag time and rafting stability

Applications

- Managing gastroesophageal reflux disease (GERD
- Localized gastric drug delivery
- Nanotechnology-Based Floating

Nanotechnology has brought forth new possibilities in FDDS development.

Controversial Issues

- Floating nanoparticles and nanospheres within polymeric matrices
- Floating beads and capsules nano-enabled
- Solubility of poorly soluble drugs using nanocarriers

Advantages

- Enhanced solubility and dissolution rate
- Improved Bio
- Controlled and Targeted Drug Delivery
- Dual Mechanism Floating

More recently, two or more gastro-retentive systems are combined for performance improvement.

Examples

- Floating + bioadhesive systems
- Floating + swelling designs
- Floating + Controlled Release Matrix Systems

Significance

- Dependence on singular retention systems decreased
- Advances in gastric retention under different physiological conditions
- 3D Printing and FDDS

Additive manufacturing has recently emerged for FDDS designs.

Major Break-Through

- 3D Printed Floating Tablets w/ Programmable Density
- Customizable drug release profiles
- Individual dosage forms

Impact

- A high degree of control over the geometry and porosity of tablets
- Patient specific
- Smart and Responsive Floating Systems

The Smart FDDS adjusts itself to physiological conditions.

Innovations

- pH-responsive floating systems
- Enzymatic activation
- Time-controlled floating behavior

They are capable of site-specific as well as time-dependent drug release.

Table No. 5: Recent Advancements in Floating Drug Delivery Systems(40,41)

Year	Type of FDDS	Drug Used	Major Findings
2016	Floating microspheres	Metformin HCl	Hollow microspheres showed prolonged floating (>12 h) and sustained drug release
2017	Hydrodynamically Balanced System (HBS)	Ofloxacin	HPMC-based HBS improved gastric retention and controlled release
2017	Floating matrix tablets	Ciprofloxacin	Enhanced bioavailability due to prolonged

			gastric retention
2018	Floating alginate beads	Metformin	Alginate–Ca^{2+} beads showed good buoyancy and sustained release
2018	Floating microspheres	Propranolol HCl	Reduced dose dumping and uniform drug release
2019	Raft-forming system	Antacid drugs	Strong raft formation is useful in GERD management
2019	Floating tablets (non-effervescent)	Famotidine	Improved bioavailability and reduced dosing frequency
2020	Floating microballoons	Metformin	Improved in vivo gastric residence and glucose control
2020	Dual-mechanism FDDS (floating + bioadhesive)	Clarithromycin	Increased gastric retention and anti-H. pylori activity
2020	Floating beads	Riboflavin	Sustained release and improved gastric retention
2021	Floating microspheres	Glipizide	Controlled release improved the antidiabetic effect
2021	Non-effervescent floating tablets	Levodopa	Prolonged gastric retention enhanced absorption
2021	Alginate raft system	GERD formulatio	Better reflux suppression than conventional antacids
2022	Floating nanoparticles	Curcumin	Improved solubility and gastric retention
2022	Floating microspheres	Domperidone	Enhanced bioavailability and sustained action
2022	3D-printed floating tablets	Baclofen	Custom geometry enabled prolonged floating and zero-order release
2023	3D-printed gastro-floating system	Verapamil HCl	Tablet shape and infill density-controlled release & buoyancy
2023	Floating hollow tablets	Metformin	In vivo studies showed >6 h gastric retention
2024	Floating microspheres (natural polymer)	Amoxicillin	Improved gastric residence for H. pylori therapy
2024	Smart floating system (pH-responsive)	Model drug	pH-triggered floating with controlled release

Future Prospects of Floating Drug Delivery Systems (FDDS)

Floating Drug Delivery Systems (FDDS) are a continually expanding domain of research in oral controlled drug delivery systems; they offer many advantages for drugs that have a small window of absorption, a short biological half-life, or for which site-specific entry in the upper GI tract is desired. In view of advances in material science, formulation, and processing methods, FDDS are expected to assume considerable importance in the development of pharmaceuticals in the years to come. One of the key areas that research in FDDS is expected to explore is the development of "smart" and "stimulus-responsive" FDDS. These systems would utilize novel polymers which could respond to changes in gastric pH values,

temperature, ion concentrations, as well as gastric contractions. This would enable these systems to ensure desired floating as well as drug release profiles regardless of changes in physiological conditions. Another promising area that is expected to assume importance is that of "nanotechnology" and FDDS coupled together. The addition of nanospheres, Nano-emulsions to FDDS would enable a marked increase in the solubility and availability of sparingly soluble actives. Nano-based advances in FDDS would be particularly useful for a wide range of actives that need to be delivered via the oral geometry, porosity, density, and drug distribution, enabling the design of customized Floating Dosage Forms. This technology is enabling personalized medicine therapies where drug dosage and delivery profiles can be designed specifically for different patients. The future studies are also emphasizing multi-mechanism Gastro-Retentive Systems, combining Floating Mechanism with other retention techniques such as Bioadhesion, Swelling, Expandable Systems, and Muco-Adhesion. The hybrid systems provide improved and consistent gastric retention, overcoming obstacles linked with Single Mechanism FDDS. The expanding application base of Biodegradable, Biocompatible, and Natural Polymers is another significant area. The use of natural polymers is ensuring enhanced safety profiles, lowering toxicity issues, and enabling sustainable drug development. Natural Polymers are also improving patient acceptability and compliance, particularly for long-term drug therapies. In clinical and regulatory contexts, future innovations in In Vitro-In Vivo Correlation (IVIVC) Methods, Imaging Modalities, and Predictive Modeling will enable a seamless transition between lab research studies and real-world drug performance. Future studies will ease faster approvals and launches related to Floating Dosage Form Design.(42)

Key Future Prospects of FDDS

Development of smart, pH- and stimuli-responsive floating systems

- Integration of nanotechnology-based carriers for improved bioavailability
- Application of 3D printing for personalized and customizable FDDS
- Design of multi-mechanism gastro-retentive systems-floatation plus bioadhesion/ swelling
- More usage of biodegradable and natural polymers
- Improved IVIVC and Advanced In-Vivo Imaging Techniques
- Improving the clinical translation and commercialization of FDDS(43)

Table No.6: Marketed Approved Floating Formulations

S. No.	Category (dosage form)	Brand / Product (active)	Short detail	Manufacturer
1	Raft-forming oral suspension (liquid)	Gaviscon Liquid (sodium alginate + antacids)	Forms floating alginate raft in stomach	Reckitt
2	Raft-forming oral suspension (liquid)	Gaviscon Advance (Liquid)	Higher-strength alginate raft liquid	Reckitt
3	Raft-forming oral suspension (liquid)	Gaviscon Double Action (Liquid)	Alginate + antacid floating liquid	Reckitt
4	Raft-forming oral suspension (liquid)	Peptac Liquid (sodium alginate + antacid)	Floating alginate antacid suspension (UK/IE market)	Various / regional distributors

5	Raft-forming oral suspension (liquid)	Rennie Liquid / Rennie Duo Liquid (alginate + antacid)	Alginate raft antacid suspension (regional brands)	Various / regional
6	Raft-forming oral suspension (liquid)	Mylanta (liquid variants with raft/alginate tech in some markets)	Marketed liquid antacid/alginate suspensions (region-dependent)	Various / regional
7	Raft-forming oral suspension (liquid)	Generic / private-label alginate raft suspensions	Multiple store brands using alginate raft technology	Various / regional manufacturers
8	Liquid in-situ gelling (oral)	Alginate in-situ gel antacid products (marketed regionally)	Liquid that gels/rafts on contact with gastric fluid	Various / regional
9	Raft-forming oral suspension (sachet / sachet liquid)	Gaviscon Sachets / Liquid sachets	Single-dose floating liquid presentations	Reckitt
10	Raft-forming oral suspension (large-pack liquid)	Gaviscon Advance (multi-pack sizes)	Pack size variants of floating raft liquid	Reckitt
11	Hydrodynamically Balanced System	Madopar HBS (levodopa + benserazide)	HBS gastro-retentive formulation for	Roche / licensees
	(HBS) — tablet/capsule		prolonged gastric residence (Parkinson's)	
12	HBS / gastric-retentive tablet (marketed HBS derivatives)	Other marketed HBS variants (levodopa families)	HBS variants derived from levodopa sustained-release programs (regional)	Roche /regional partners
13	Floating microsphere / microencapsulated commercial platforms	Commercial hollow microsphere/microencapsulation products (niche/industrial use)	Some microencapsulation platforms are marketed for sustained/floatable delivery in niche products	Various specialty manufacturers
14	Floating microballoons (industrial/commercial examples)	Microballoon-based sustained-release products (niche markets)	Hollow microballoon technologies used in some commercial formulations	Various / contract manufacturers

15	Floating raft antacid — pharmacy brands	Peptac / Rennie / Gaviscon generic equivalents (liquid)	Marketed raft liquids under multiple trade names worldwide	Various / regional
16	Raft-forming oral suspension (medical/OTC)	Alginate antacid liquid (hospital OTC brands)	Alginate raft liquids sold for clinical/hospital use	Various manufacturers
17	In-situ gelling oral (gel/solution)	Regional alginate gel formulations (therapeutic liquid gels)	Marketed as antacid/gastro-protective in some countries	Various / regional
18	Liquid raft antacid (flavoured / multipack)	Gaviscon flavour & pack variants (liquid)	Flavour and pack SKUs of the floating suspension	Reckitt
19	Liquid raft antacid (OTC private label)	Supermarket / pharmacy private-label alginate suspensions	Private-label floating antacid liquids	Various / regional
20	Raft-forming oral suspension (paediatric liquid)	Gaviscon Infant / infant alginate suspensions	Paediatric formulations that form floating gel/raft	Reckitt /regional licensees

CONCLUSION

Floating Drug Delivery Systems have now been established as a safe, effective, and modern approach for improving oral drug delivery. The concept of prolonging gastric residence time has been successfully employed in FDDS to increase bioavailability, give sustained plasma drug concentrations, decrease frequent doses, and suppress adverse reactions, especially for drugs primarily absorbed in the stomach and upper GI tract. The employment of appropriate polymers, effervescent and non-effervescent formulations, and appropriate formulation methodologies is also known to ensure efficient buoyancy and sustained drug release. Commercially available alginate-based raft tablets and hydrodynamically balanced formulations have already proven the efficacy and practical viability of FDDS in clinical applications. Moreover, new approaches in micro- and nanotechnology and smart and stimulus-responsive materials and innovative 3D printing methodologies have now opened up new avenues for personalized and goal-oriented therapy using FDDS in forthcoming generations of oral drug-delivery systems despite some drawbacks in certain applications.

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