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# Floating drug delivery systems: A review

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## ABSTRACT

The purpose of writing this review on floating drug delivery systems (FDDS) was to compile the recent literature with special focus on the principal mechanism of floatation to achieve gastric retention. The recent developments of FDDS including the physiological and formulation variables affecting gastric retention, approaches to design single-unit and multiple-unit floating systems, and their classification and formulation aspects are covered in detail. This review also summarizes the in vitro techniques, *in vivo* studies to evaluate the performance and application of floating systems, and applications of these systems. These systems are useful to several problems encountered during the development of a pharmaceutical dosage form. 

## KEYWORDS

Floating drug delivery systems;
Single unit;
Multiple units;
Evaluation *in vitro*;
*in vivo*.

## 1. INTRODUCTION

Davis 1968 firstly described the concept of floating drug delivery systems after experiencing gagging or choking by some person, while swallowing medicinal pills. The researchers suggested that such difficulty could be overcome by providing pills having density of less than 1.0 g/ml, so that the pill floats on the surface. Since then several approaches have been proposed for ideal floating drug delivery system[1].

Gastric emptying of dosage forms is an extremely variable process and ability to prolong and control the emptying time is a valuable asset for dosage forms, which reside in the stomach for a longer period of time than conventional dosage forms. Several difficulties are faced in designing controlled release systems for better absorption and enhanced bioavailability. One of such difficulties is the inability to confine the dosage form in the desired area of the gastrointestinal tract. Drug absorption from the gastrointestinal tract is a complex procedure and is subject to many variables. It is widely acknowledged that the extent of gastrointestinal tract drug absorption is related to contact time with the small intestinal mucosa[2].

Gastro retentive systems can remain in the gastric region for several hours and hence significantly prolong the gastric residence time of drugs. Prolonged gastric retention improves bioavailability, reduces drug waste, and improves solubility for drugs that are less soluble in a high pH environment. The controlled gastric retention of solid dosage forms may be achieved by the mechanisms of mucoadhesion[3,4], flotation[5], sedimentation[6,7], expansion[8,9], modified shape systems[10,11], or by the simultaneous administration of pharmacological agents[12,13] that delay gastric emptying[14].

These dosage forms are particularly appropriate for drugs

a. Act locally in the stomach
b. Primarily absorbed in the stomach
c. Poorly soluble at an alkaline pH

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d. Narrow window of absorption
e. Unstable in the intestinal or colonic environment[15].

## 2. Gastric emptying

Anatomically the stomach is divided into 3 regions: fundus, body, and antrum (pylorus). The proximal part made of fundus and body acts as a reservoir for undigested material, whereas the antrum is the main site for mixing motions and act as a pump for gastric emptying by propelling actions[16].

Gastric emptying occurs during fasting as well as fed states. The pattern of motility is however distinct in the 2 states. During the fasting state an interdigestive series of electrical events take place, which cycle both through stomach and intestine every 2 to 3 hours[17]. This is called the interdigestive myloelectric cycle or migrating myloelectric cycle (MMC), which is further divided into following 4 phases as described by Wilson and Washington[18].

a. Phase I (basal phase) lasts from 40 to 60 minutes with rare contractions.
b. Phase II (preburst phase) lasts for 40 to 60 minutes with intermittent action potential and contractions. As the phase progresses the intensity and frequency also increases gradually.
c. Phase III (burst phase) lasts for 4 to 6 minutes. It includes intense and regular contractions for short period. It is due to this wave that all the undigested material is swept out of the stomach down to the small intestine. It is also known as the housekeeper wave.
d. Phase IV lasts for 0 to 5 minutes and occurs between phases III and I of 2 consecutive cycles.

After the ingestion of a mixed meal, the pattern of contractions changes from fasted to that of fed state. This is also known as digestive motility pattern and comprises continuous contractions as in phase II of fasted state. These contractions result in reducing the size of food particles (to less than 1 mm), which are propelled toward the pylorus in a suspension form. During the fed state onset of MMC is delayed resulting in slowdown of gastric emptying rate[19].

Scintigraphic studies determining gastric emptying rates revealed that orally administered controlled release dosage forms are subjected to basically 2 complications, that of short gastric residence time and unpredictable gastric emptying rate[14].

## 3. Approaches to increase gastric retention

### a. Floating drug delivery systems (FDDS)

FDDS or Hydrodynamically Balanced Systems (HBS) have a bulk density lower than gastric fluids and therefore remain floating in the stomach unflattering the gastric emptying rate for a prolonged period. The drug is slowly released at a desired rate from the floating system and after the complete release the residual system is expelled from the stomach. This leads to an increase in the GRT and a better control over fluctuations in plasma drug concentration[20].

### b. Swelling and expanding systems or plug type systems

Swellable systems include the products that swell after swallowing to an extent that prevents their exit from through the pylorus. This results in retention of dosage form in stomach for prolonged period. These systems maybe called plug type systems as they show a tendency to remain lodged at the pyloric spincter[21,22].

### c. Modified shape systems

Modified systems are non disintegrating geometric shapes made up of silastic elastomer or extruded from polyethylene blends, which prolong the GRT, depending on size and shape[23-27].

### d. Bioadhesive systems

In this approach bioadhesive polymers are used that can adhere to the epithelial surface of GIT. Mechanistically bioadhesion involves the formation of hydrogen and electrostatic bonding at the mucous polymer interface ( Wilson and Washington, 1989)[28-31].

### e. High density systems

These systems include coated pellets that have a density greater than the stomach contents (1.004 gm/$cm^3$). This can be achieved by coating the drug with heavy inert material such as zinc oxide, titanium dioxide, barium sulfate, etc.[32-34].

### f. Other delaying gastric emptying devices

Other approaches for delayed gastric emptying include feeding of some indigestible polymers[35-37] or fatty acid salts[38,39], which can change the motility of GI tract leading to an increase in GRT and hence prolonged drug release[1].

## 4. Factors affecting gasrric retention

### a. Density

The density of a dosage form also affects the gastric emptying rate. A buoyant dosage form having a density of less than that of the gastric fluids floats. Since it is away from the pyloric sphincter, the dosage unit is retained in the stomach for a prolonged period[14].

### b. Size of dosage form

Dosage form units with a diameter of more than 7.5mm are reported to have an increased GRT compared with those with a diameter of 9.9mm.

### c. Shape of dosage form

Tetrahedron and ring-shaped devices with a flexural modulus of 48 and 22.5 kilo pounds per square inch (KSI) are reported to have better GRT ≈ 90% to 100% retention at 24 hours compared with other shapes[40].

### d. pH

The pH of the stomach in fasting state is ~1.5 to 2.0 and in fed state is 2.0 to 6.0. A large volume of water administered with an oral dosage form raises the pH of stomach contents to 6.0 to 9.0. Stomach doesn't get time to produce sufficient acid when the liquid empties the stomach, hence generally basic drugs have a better chance of dissolving in fed state than in a fasting state[14].

### e. Single or multiple unit formulation

Multiple unit formulations show a more predictable release profile and insignificant impairing of performance due to failure of units, allow co-administration of units with different release profiles or containing incompatible substances and permit a larger margin of safety against dosage form failure compared with single unit dosage forms.

### f. Fed or unfed state

Under fasting conditions, the GI motility is characterised by periods of strong motor activity or the migrating myoelectric complex (MMC) that occurs every 1.5 to 2 hours. The MMC sweeps undigested material from the stomach and, if the timing of administration of the formulation coincides with that of the MMC, the GRT of the unit can be expected to be very short. However, in the fed state, MMC is delayed and GRT is considerably longer.

### g. Nature of meal

Feeding of indigestible polymers or fatty acid salts can change the motility pattern of the stomach to a fed state, thus decreasing the gastric emptying rate and prolonging drug release.

### h. Caloric content

GRT can be increased by four to 10 hours with a meal that is high in proteins and fats.

### i. Concomitant drug administration

Anticholinergics like atropine and propantheline, opiates like codeine and prokinetic agents like metoclopramide and cisapride.

### j. Age

Elderly people, especially those over 70, have a significantly longer GRT.

### k. Posture

GRT can vary between supine and upright ambulatory states of the patient.

### l. Gender

Mean ambulatory GRT in males (3.4±0.6 hours) is less compared with their age and race-matched female counterparts (4.6±1.2 hours), regardless of the weight, height and body surface).

### m. Biological factor

Diabetes and Crohn's disease, etc[40].

### n. Volume

The resting volume of the stomach is 25 to 50 mL. Volume of liquids administered affects the gastric emptying time. When volume is large, the emptying is faster. Fluids taken at body temperature leave the stomach faster than colder or warmer fluids[14].

Timmermans et al studied the effect of buoyancy, posture, and nature of meals on the gastric emptying process in vivo using gamma scintigraphy[41]. To perform these studies, floating and non floating capsules of 3 different sizes having a diameter of 4.8 mm (small units), 7.5 mm (medium units), and 9.9 mm (large units), were formulated. On comparison of floating and nonfloating dosage units, it was concluded that regardless of their sizes the floating dosage units remained

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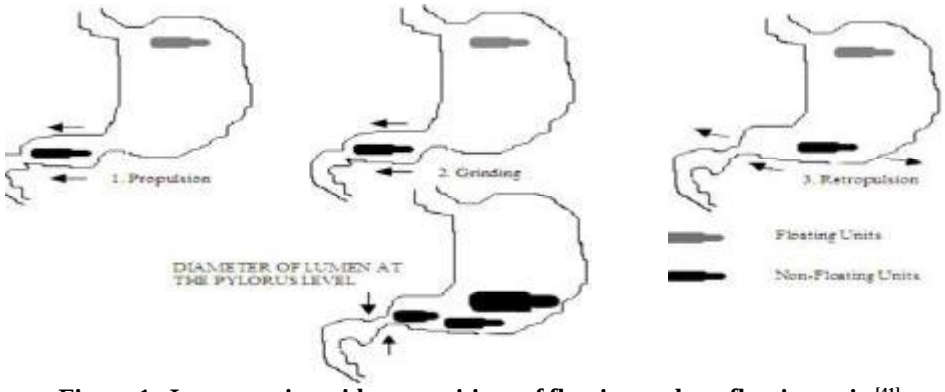


**Figure 1 : Intragastric residence positions of floating and nonfloating units[41]**

buoyant on the gastric contents throughout their residence in the gastrointestinal tract, while the nonfloating dosage units sank and remained in the lower part of the stomach. Floating units away from the gastro-duodenal junction were protected from the peristaltic waves during digestive phase while the nonfloating forms stayed close to the pylorus and were subjected to propelling and retropelling waves of the digestive phase. It was also observed that of the floating and nonfloating units, the floating units were had a longer gastric residence time for small and medium units while no significant difference was seen between the 2 types of large unit dosage forms.

## 5. Approaches to design fdds

1. Single-unit dosage forms
2. Multiple-unit dosage forms

### 5.1. Single-unit dosage forms

In Low-density approach[5] the globular shells apparently having lower density than that of gastric fluid can be used as a carrier for drug for its controlled release. A buoyant dosage form can also be obtained by using a fluid-filled system that floats in the stomach. In coated shells[42] popcorn, pop rice, and polystyrol have been exploited as drug carriers. Sugar polymeric materials such as methacrylic polymer and cellulose acetate phthalate have been used to undercoat these shells. These are further coated with a drug-polymer mixture. The polymer of choice can be either ethylcellulose or hydroxy propyl cellulose depending on the type of release desired. Finally, the product floats on the gastric fluid while releasing the drug gradually over a prolonged duration.

Fluid- filled floating chamber[43] type of dosage forms includes incorporation of a gas-filled floatation chamber into a microporous component that houses a drug reservoir. HBS of chlordiazeopoxide hydrochloride[44] had comparable blood level time profile as of three 10-mg commercial capsules. HBS can either be formulated as a floating tablet or capsule. Many polymers and polymer combinations with wet granulation as a manufacturing technique have been explored to yield floatable tablets.

Various types of tablets (bilayered and matrix) have been shown to have floatable characteristics. Some of the polymers used are hydroxy propyl cellulose, hydroxy propyl methylcellulose, cross povidone, sodium carboxy methyl cellulose, and ethyl cellulose. Self-correcting floatable asymmetric configuration drug delivery system[45] employs a disproportionate 3-layer matrix technology to control drug release. Single-unit formulations are associated with problems such as sticking together or being obstructed in the gastrointestinal tract, which may have a potential danger of producing irritation[14].

### 5.2. Multiple-unit dosage forms

The purpose of designing multiple-unit dosage form is to develop a reliable formulation that has all the advantages of a single-unit form and also is devoid of any of the above mentioned disadvantages of single-unit formulations. In pursuit of this endeavor many multiple-unit floatable dosage forms have been designed. Micro spheres have high loading capacity and many polymers have been used such as albumin, gelatin, starch, polymethacrylate, polyacrylamine, and poly alkyl cyano acrylate. Spherical polymeric microsponges, also referred to as "microballoons" have been prepared. Microspheres have a characteristic internal hollow structure and show an excellent *in vitro* floatability[46]. In

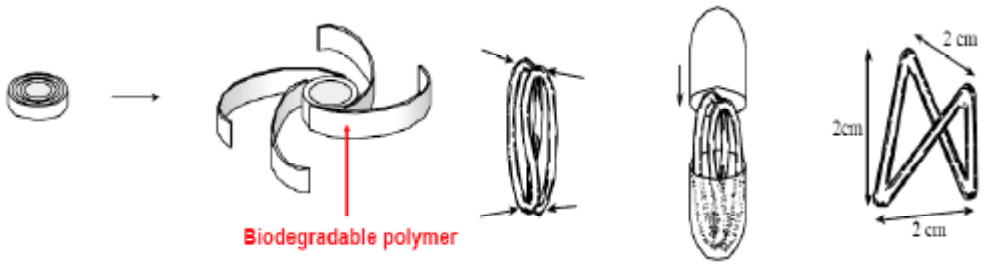


**Figure 2: Expansive Gastro retentive dosage forms[1]**

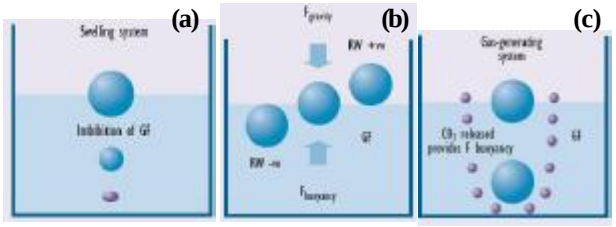


**Figure 3: The mechanism of floating systems[40]**
**GF = Gastric fluid**

Carbon dioxide–generating multiple-unit oral formulations[47] several devices with features that extend, unfold, or are inflated by carbon dioxide generated in the devices after administration have been described in the recent patent literature. These dosage forms are excluded from the passage of the pyloric sphincter if a diameter of ~12 to 18 mm in their expanded state is exceeded[14].

## 6. Formulation development of fdds

Comprehensive knowledge about GI dynamics such as gastric emptying , small intestine transit, colonic transit, etc., is key for the optimum design of a oral controlled dosage form[48]. Knowledge about the rate and extent of drug absorption from different sites of GI tract and factors that govern the absorption further assist the design of dosage form.

3 major requirements for FDDS formulations are:

1. It must form a cohesive gel barrier.
2. It must maintain specific gravity lower than gastric contents.
3. It should release contents slowly to serve as a reservoir.

Selection of excipients is an important strategic decision for designing a dosage form with consistence and controlled residence in the stomach[1].

## 7. Advantages

### 7.1. ustained drug delivery

Hydrodynamically Balanced Systems can remain in the stomach for long periods and hence can release the drug over a prolonged period of time. The problem of short gastric residence time encountered with an oral CR formulation hence can be overcome with these systems. These systems have a bulk density of <1 as a result of which they can float on the gastric contents. These systems are relatively large in size and passing from the pyloric opening is prohibited.

Recently sustained release floating capsules of nicardipine hydrochloride were developed and were evaluated *in vivo*. The formulation compared with commercially available MICARD capsules using rabbits. Plasma concentration time curves showed a longer duration for administration (16 hours) in the sustained release floating capsules as compared with conventional MICARD capsules (8 hours)[49].

Similarly a comparative study[50] between the Madopar HBS and Madopar standard formulation was done and it was shown that the drug was released up to 8 hours *in vitro* in the former case and the release was essentially complete in less than 30 minutes in the latter case.

### 7.2. Site-specific drug delivery

These systems are particularly advantageous for drugs that are specifically absorbed from stomach or the proximal part of the small intestine, e.g. riboflavin and furosemide.

Furosemide is primarily absorbed from the stomach followed by the duodenum. It has been reported that a monolithic floating dosage form with prolonged gastric residence time was developed and the bioavailability was increased. AUC obtained with the floating tablets was approximately 1.8 times those of conventional furosemide tablets[51].

A bilayer-floating capsule was developed for local delivery of misoprostol, which is a synthetic analog of prostaglandin E1 used as a protectant of gastric ulcers caused by administration of NSAIDs. By targeting slow

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delivery of misoprostol to the stomach, desired therapeutic levels could be achieved and drug waste could be reduced[52].

### 7.2. Absorption enhancement

Drugs that have poor bioavailability because of site-specific absorption from the upper part of the gastrointestinal tract are potential candidates to be formulated as floating drug delivery systems, thereby maximizing their absorption.

A significant increase in the bioavailability of floating dosage forms (42.9%) could be achieved as compared with commercially available LASIX tablets (33.4%) and enteric-coated LASIX-long product (29.5%)[51].

## 8. Limitations

1. They require a sufficiently high level of fluids in the stomach, for enabling the system to float and to work efficiently.
2. They are not suitable for drugs with stability or solubility problem in stomach.
3. Drugs with irritant effect on gastric mucosa also limit the applicability of FDDS[1].

## 9. Expansive gastroretentive dosage forms

This is the class of gastro retentive systems capable of expanding in stomach. The expanded structure is trapped in stomach for prolonged period leading to sustained drug release and subsequent controlled absorption in stomach and intestine[1].

## 10. Altered density dosage forms

Apart from shape and size, specific density of delivery system also regulates the GRT. It was concluded that multiple unit formulations are less affected by the presence of food than single unit formulations since these subunits are distributed through out the GI tract[33].

Studies have shown that increasing the density from 1.0 to 1.6 prolongs average time from 7-25 h. Gastric residence time can be improved by altering the density, i.e.,

1. High density fast sedimenting type.
2. Low density floating systems[1].

### 10.1. High density or non-floating drug delivery systems

This approach involves formulation of dosage forms with the density that must exceed density of normal stomach content[53]. These formulations are prepared by coating drug on a heavy core or mixed with heavy inert materials such as iron powder, zinc oxide, and barium sulfate. These resultant pellets can be coated with diffusion controlled membrane[1].

### 10.2. Low density or floating drug delivery systems (FDDS) Or HBS

This approach exploits the floating property of substances with density lower than the fluid medium. Floating drug delivery systems further divided into 2 main categories[1].

### Definition

Floating drug delivery systems (FDDS) have a bulk density less than gastric fluids and so remain buoyant in the stomach without affecting the gastric emptying rate for a prolonged period of time. While the system is floating on the gastric contents (see Figure a), the drug is released slowly at the desired rate from the system.

After release of drug, the residual system is emptied from the stomach. This results in an increased GRT and a better control of the fluctuations in plasma drug concentration.

However, besides a minimal gastric content needed to allow the proper achievement of the buoyancy retention principle, a minimal level of floating force (F) is

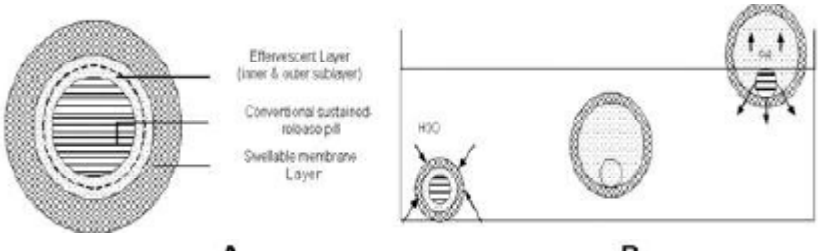


**Figure 4: (A) Multiple-unit oral floating drug delivery system. (B) Working principle of effervescent floating drug delivery system[54]**


**Figure 5: Schematic presentation of working of a triple-layer system. (A) Initial configureuration of triple-layer tablet. (B) On contact with the dissolution medium the bismuth layer rapidly dissolves and matrix starts swelling. (C) Tablet swells and erodes. (D) And (E) Tablet erodes completely[55]**

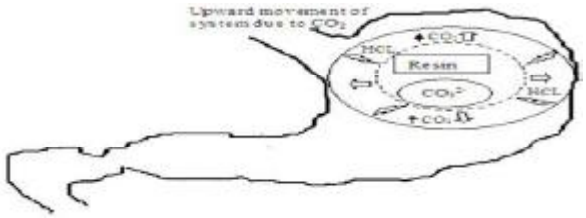


**Figure 6: Pictorial presentation of working of effervescent floating drug delivery system based on ion exchange resin[56]**

also required to keep the dosage form reliably buoyant on the surface of the meal. To measure the floating force kinetics, a novel apparatus for determination of resultant weight (RW) has been reported.

The RW apparatus operates by measuring continuously the force equivalent to F (as a function of time) that is required to maintain the submerged object. The object floats better if RW is on the higher positive side (see Figure b). This apparatus helps in optimizing FDDS with respect to stability and durability of floating forces produced in order to prevent the drawbacks of unforeseeable intragastric buoyancy capability variations.

**RW or F = F buoyancy - F gravity**

**= (Df - Ds) gV,**

where (RW = total vertical force, Df = fluid density, Ds = object density, V = volume and g =acceleration due to gravity)[40].

## 11. Classification of floating drug delivery systems

1. Effervescent floating dosage forms
2. Non-effervescent floating dosage forms

### 11.1. Effervescent floating dosage forms

These are matrix types of systems prepared with the help of swellable polymers such as methylcellulose and chitosan and various effervescent compounds, e.g. sodium bicarbonate, tartaric acid, and citric acid. They are formulated in such a way that when in contact with the acidic gastric contents, Carbondioxide ($CO_2$) is liberated and gets entrapped in swollen hydrocolloids, which provides buoyancy to the dosage forms.

Ichikawa et al[54] developed a new multiple type of floating dosage system composed of effervescent layers and swellable membrane layers coated on sustained release pills. The inner layer of effervescent agents containing sodium bicarbonate and tartaric acid was divided into 2 sublayers to avoid direct contact between the 2 agents. These sub layers were surrounded by a swellable polymer membrane containing polyvinyl acetate and purified shellac. When this system was immersed in the buffer at $37^0$C, it settled down and the solution permeated into the effervescent layer through the outer swellable membrane. $CO_2$ was generated by the neutralization reaction between the 2 effervescent agents, producing swollen pills (like balloons) with a density less than 1.0 g/mL. It was found that the system had good floating ability independent of pH and viscosity and the drug (para-amino benzoic acid) released in a sustained manner[54].

Yang et al[55] developed a swellable asymmetric triple-layer tablet with floating ability to prolong the gastric residence time of triple drug regimen (tetracycline, metronidazole, and clarithromycin) in Helicobacter pylori-associated peptic ulcers using hydroxy propyl methyl cellulose (HPMC) and poly (ethylene oxide) (PEO) as the rate-controlling polymeric membrane excipients. The design of the delivery system was based on the swellable asymmetric triple-layer tablet approach. Hydroxy propyl methyl cellulose and poly (ethylene oxide) were the major rate-controlling polymeric excipients. Tetracycline and metronidazole were incorporated into the core layer of the triple-layer matrix for controlled delivery, while bismuth salt was included in one of the outer layers for instant release. The floatation was accomplished by incorporating gas-generating layer consisting of sodium bicarbonate: calcium carbonate (1:2 ratios) along with the polymers. The in vitro results revealed that the sustained delivery of tetracycline and metronidazole over 6 to 8 hours could be achieved while the tablet remained afloat. The floating feature aided in prolonging the gastric residence time of this system to maintain high-localized concentration of tetracycline and

metronidazole.

Atyabi and coworkers[56] developed a floating system using ion exchange resin that was loaded with bicarbonate by mixing the beads with 1 M sodium bicarbonate solution. The loaded beads were then surrounded by a semipermeable membrane to avoid sudden loss of $CO_2$. Upon coming in contact with gastric contents an exchange of chloride and bicarbonate ions took place that resulted in $CO_2$ generation thereby carrying beads toward the top of gastric contents and producing a floating layer of resin beads. The *in vivo* behavior of the coated and uncoated beads was monitored using a single channel analyzing study in 12 healthy human volunteers by gamma radio scintigraphy. Studies showed that the gastric residence time was prolonged considerably (24 hours) compared with uncoated beads (1 to 3 hours).

### 11.2. Non-effervescent floating dosage forms

Non-effervescent floating dosage forms use a gel forming or swellable cellulose type of hydrocolloids, polysaccharides, and matrix-forming polymers like polycarbonate, polyacrylate, polymethacrylate, and polystyrene. The formulation method includes a simple approach of thoroughly mixing the drug and the gel-forming hydrocolloid. After oral administration this dosage form swells in contact with gastric fluids and attains a bulk density of < 1. The air entrapped within the swollen matrix imparts buoyancy to the dosage form. The so formed swollen gel-like structure acts as a reservoir and allows sustained release of drug through the gelatinous mass.

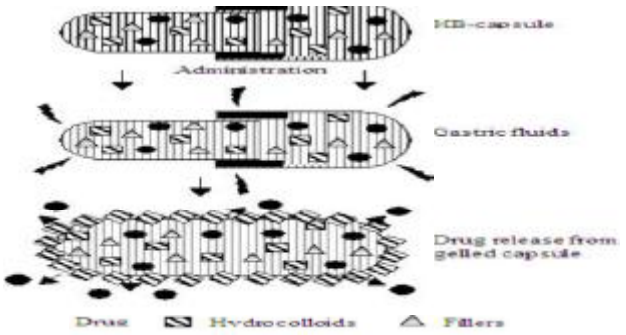


**Figure 7: Working principle of hydro dynamically balanced system[44]**

Nur and Zhang[57] developed floating tablets of captopril using HPMC (4000 and 15 000 cps) and carbopol 934P. In vitro buoyancy studies revealed that tablets of 2 kg/cm2 hardness after immersion into the floating media floated immediately and tablets with hardness 4 kg/cm2 sank for 3 to 4 minutes and then came to the surface. Tablets in both cases remained floating for 24 hours. The tablet with 8 kg/cm2 hardness showed no floating capability. It was concluded that the buoyancy of the tablet is governed by both the swelling of the hydrocolloid particles on the tablet surface when it contacts the gastric fluids and the presence of internal voids in the center of the tablet (porosity). A prolonged release from these floating tablets was observed as compared with the conventional tablets and a 24-hour controlled release from the dosage form of captopril was achieved.

Sheth and Tossounian[44] developed an HBS system containing a homogeneous mixture of drug and the hydrocolloid in a capsule, which upon contact with gastric fluid acquired and maintained a bulk density of less than 1 thereby being buoyant on the gastric contents of stomach until all the drug was released.

Sheth and Tossounian[58] developed hydro dynami-

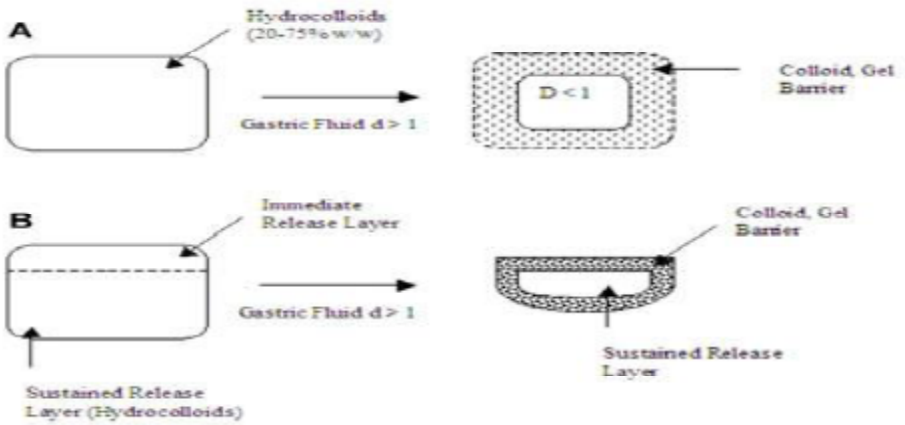


**Figure 8: Intra gastric floating tablets. (A) United states patent 4 167 558, September 11, 1979. (B) United States patent 4 140 755, February 20, 1979[58]**

**TABLE 1: *In vitro* floating and dissolution performance[59]**

| Drug (Polymer used) | Floating Media/Dissolution medium and method | Ref |
|---|---|---|
| Pentoxyfillin (HPMC K4 M) | 500 mL of artificial gastric fluid pH 1.2 (without pepsin) at 100 rpm using USP XXIII dissolution apparatus. The time taken by the tablet to emerge on the water surface (floating lag time) and time until it floats on water surface was measured. | [60] |
| Amoxicillin beads (Calcium alginate) | For dissolution: 900 mL of deaerated 0.1 M HCl (pH 1.2) at 37ºC ± 1ºC in USP XXII dissolution tester at 50 rpm. | [61] |
| Ketoprofen (Eudragit S100 Eudragit RL) | 20 mL of simulated gastric fluid without pepsin, 50 mg of floating microparticles in 50-mL beakers were shaken horizontally in a water bath. % age of floating micro particles was calculated. For dissolution: 900 mL of either 0.1 N HCl or the phosphate buffer (pH 6.8) at 37ºC ± 0.1ºC in USP dissolution apparatus (I) at 100 rpm. | [62] |
| Verapamil (Propylene foam, Eudragit RS, ethyl cellulose, poly methyl meth acrylate) | 30 mL of 0.1 N HCl (containing 0.02% wt/wt Tween 20), pH 1.2. Floatation was studied by placing 60 particles into 30-mL glass flasks. Number of settled particles was counted. | [63] |
| Captopril (Methocel K4M) | 900 mL of enzyme-free 0.1 N HCl (pH 1.2) in USP XXIII apparatus II (basket method) at 37ºC at 75 rpm. | [57] |
| Theophylline (HPMC K4M, Polyethylene oxide) | 0.1 N HCl in USP XXIII Apparatus II at 50 rpm at 37°C. Its buoyancy to upper 1/3 of dissolution vessel was measured for each batch of tablet. | [45] |
| Furosemide (β Cyclodextrin, HPMC 4000, HPMC 100,CMC, Polyethylene glycol) | For dissolution: continuous flow through cell gastric fluid of pH 1.2, 45–50 m N/m by adding 0.02% Polysorbate 20 (to reduce the surface tension), the flow rate to provide the sink conditions was 9mL/min. | [64] |
| Aspirin, Griseofulvin, p-Nitro Aniline (polycarbonate, PVA) | For dissolution: 500 mL of simulated gastric and intestinal fluid in 1000-mL Erlenmeyer flask. Flasks were shaken in a bath incubator at 37ºC. | [65] |
| Piroxicam (microspheres) (Polycarbonate) | For dissolution: 900 mL dissolution medium in USP paddle type apparatus at 37ºC at 100 rpm. | [66] |

**TABLE 2: *In vivo* evaluation: [59]**

| Drug (Polymer) | Method | Ref |
|---|---|---|
| Tranilast (Eudragit S (BaSo4)) | Two healthy male volunteers administered hard gelatin capsules packed with microballons (1000 mg) with 100 mL water. X-ray photographs at suitable intervals were taken. | [68] |
| Isardipine (HPMC) | Two phases: Phase I (fasted conditions): Five healthy volunteers (3 males and 2 females) in an open randomized crossover design, capsules ingested in sitting position with 100 mL of tap water. Phase II (fed states): Four subjects received normal or MR capsules in a crossover design after standard breakfast. Venous blood samples were taken in heparinized tubes at predetermined time intervals after dosing. | [69] |
| Hydrogel composites | Dogs (50 lbs) kept fasted and fed conditions. In each experiment (fed or fasted) 300 mL of water was given before administration of the capsules; X-ray pictures were taken. | [70] |
| Amoxycillin trihydrate | Six healthy fasted male subjects were selected; serum drug levels were compared in a single-dose crossover study following administration of tablets/capsules. | [61] |
| Floating beads | Gamma scintigraphy: *In vivo* behavior of coated and uncoated beads was monitored using a single channel analyzing study in 12 healthy human volunteers of mean age 34 yrs (22–49). | [56] |
| Pentoxyfillin | Four healthy beagle dogs (fasted for 24 hours). Tablet was administered with 100 mL of water for radiographic imaging. The animal was positioned in a right lateral/ventrodorsal recumbency. | [60] |

cally balanced sustained release tablets containing drug and hydrophilic hydrocolloids, which on contact with gastric fluids at body temperature formed a soft gelatinous mass on the surface of the tablet and provided a water-impermeable colloid gel barrier on the surface of the tablets. The drug slowly released from the surface of the gelatinous mass that remained buoyant on gastric fluids.

**Some of the marketed formulations are listed as follows**

Review

a. Valrelease ® - Floating capsule of diazepam
b. Madopar® - Benserazide and L-Dopa combination formulation
c. Liquid Gaviscon® -Floating liquid alginate preparations
d. Topalkan®- aluminium - Magnesium antacid preparation
e. Almagate Flot-Coat® -Antacid preparation[40]

**Evaluation of floating drug delivery systems**

Various parameters[59] that need to be evaluated in gastro-retentive formulations include floating duration, dissolution profiles, specific gravity, content uniformity, hardness, and friability in case of solid dosage forms. In the case of multiparticulate drug delivery systems, differential scanning calorimetry (DSC), particle size analysis, flow properties, surface morphology, and mechanical properties are also performed.

The tests for floating ability and drug release are generally performed in simulated gastric fluids at $37^0$C. $^{In\ vivo}$ gastric residence time of a floating dosage form is determined by X-ray diffraction studies, gamma scintigraphy[41] or roentgenography[67].

## CONCLUSION

In Gastro Intestinal Tract the drug absorption is highly variable process. For better drug absorption gastric retention is very important. Prolonging the gastric retention of the dosage form enhances or extends the drug absorption. One of the important approaches to improve the gastric retention is Floating Drug Delivery. Even though many hurdles are there many pharmaceutical scientists working on Floating Drug Delivery Systems to improve the gastric retention.

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