RESEARCH ARTICLE

Development And Characterization of Floating Sustained-Release Tablets of an Anti-Diabetic Drug

Abhijeet Welankiwar[1*], Vaishnavi Sitre[2], Dipti Ruikar[3], Dipti Bonde[4]

[1]Associate Professor, Department of Pharmaceutical Chemistry, P. R. Pote Patil College of Pharmacy, Amravati Pote Estate Pote Patil Road Kathora Amravati Maharashtra 444604.

[2]Research Scholar, P. R. Pote Patil College of Pharmacy, Amravati Pote Estate Pote Patil Road Kathora Amravati Maharashtra 444604.

[3]Professor, Department of Quality Assurance, P. R. Pote Patil College of Pharmacy, Amravati Pote Estate Pote Patil Road Kathora Amravati Maharashtra 444604.

[4]Associate Professor, Department of Pharmacology, P. R. Pote Patil College of Pharmacy, Amravati Pote Estate Pote Patil Road Kathora Amravati Maharashtra 444604.

Corresponding Author Email ID: Eabhi123welankiwar@gmail.com

Received: 26/04/2026 **Accepted:** 29/05/2026 **Published:** 15/07/2026

Abstract

The present work focuses on Prototype Formulation with regards to development and evaluation of a sustained release floating tablet of glibenclamide for improved management of type 2 diabetes mellitus. Glibenclamide is known for its poor solubility, short half-life, and narrow therapeutic index, which often cause fluctuations in blood drug levels when taken in standard forms. To overcome these issues, Developed The gastroretentive floating system using hydrophilic polymers (HPMC K4M and K15M) along with effervescent agents like sodium bicarbonate and citric acid. The tablets were made by direct compression and tested for key properties such as hardness, friability, weight consistency, swelling behavior, floating lag time, and total floating duration. Dissolution studies were performed in 0.1N HCl using USP II apparatus. A 3^2 factorial design was applied to optimize polymer and gas-generating agent concentrations. The best formulation showed quick buoyancy with minimal lag, remained afloat for up to 15 hours, and released about 78–85% of the drug over 8 hours. The release pattern followed a non-Fickian diffusion mechanism, involving both drug diffusion and polymer erosion. Risk assessment using FMEA emphasized the need for a precise balance between polymer and effervescent agent levels to achieve the desired floating and release characteristics. Overall, the developed floating tablet improved gastric retention, ensured sustained release, and enhanced the therapeutic effect of glibenclamide, offering a promising strategy for better glycemic control in type 2 diabetes.

Keywords: Gastroretentive Floating drug delivery, HPMC K4M and K15M, Glibenclamide, Factorial Design, non-Fickian diffusion mechanism.

Journal of Applied Pharmaceutical Sciences and Research, (2026); DOI: 10.31069/japsr.v9i2.08

Introduction

Diabetes mellitus is a heterogeneous group of metabolic disorders characterized by chronic hyperglycemia arising from defects in insulin secretion, insulin action, or both[1]. Oral sulfonylureas such as Glibenclamide are widely used in the management of type 2 diabetes mellitus due to their insulin secretagogue activity[1]. However, glibenclamide exhibits pharmacokinetic limitations, including relatively short biological half-life, variable gastrointestinal absorption, and a narrow therapeutic index. Conventional immediate-release formulations Pass rapidly through GI tract resulting in reduced absorption and fluctuations in plasma drug concentration, increasing the risk of dose-dependent adverse effects such as hypoglycemia and reducing overall therapeutic efficiency[3].To address these challenges. Sustained release formulations are designed to modulate the drug release kinetics, thereby maintaining steady-state plasma concentrations within the therapeutic window for extended durations[4].This extended retention enhances drug dissolution and absorption, particularly for poorly soluble drugs like glibenclamide, ultimately improving bioavailability and therapeutic efficacy [5]. Thus, the development of sustained release floating formulations represents a rational and effective approach for optimizing the pharmacokinetic and pharmacodynamic performance of glibenclamide in the management of diabetes mellitus[5]. Floating sustained release tablets overcome these limitations by prolonging gastric residence time and providing controlled release of the drug. 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. 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. Glibenclamide is a potent oral hypoglycaemic agent belonging to sulphonyl urea class. It causes hypoglycaemia by stimulating insulin release from the beta cells of the pancreas. It may further increase insulin level by reducing hepatic clearance of the hormone [11]. glibenclamide belongs to class II (i.e. drugs with low solubility and high permeability). It is practically insoluble in water and consequently, its dissolution has been considered to be the rate limiting step for absorption. Being weak acid with a pka 5.3, its solubility is pH dependant and its absorption is expected to be better from the upper part of the gastrointestinal tract (GIT). Dissolution testing is a vital quality control parameter in pharmaceutical development, providing insight into the rate and extent of drug release from dosage forms. Dissolution studies also play a significant role in ensuring batch-to-batch consistency, formulation optimization, and compliance with regulatory requirements. Among various analytical techniques, UV spectrophotometry is one of the most commonly employed methods for quantifying drug release in dissolution studies due to its simplicity, sensitivity, rapidity, and cost-effectiveness. UV spectrophotometry suitable for routine analysis of drug concentration in dissolution media at a selected wavelength (λmax) [10]. Method development for dissolution testing involves careful selection of dissolution parameters such as dissolution medium, apparatus type, agitation speed, temperature, and sampling intervals. These parameters are optimized to simulate physiological conditions and to ensure reproducibility of results. Simultaneously, the UV spectrophotometric method must be developed and validated to confirm its accuracy, precision, specificity, linearity, and robustness. Potential interference from excipients, stability of the drug in dissolution medium, and solvent compatibility must also be evaluated during the method development process. Therefore, a well-developed and validated dissolution method using UV spectrophotometry is crucial for ensuring the quality, safety, and efficacy of pharmaceutical products [10].

Material and Methods

Materials

Glibenclamide is obtained from gift sample of Reputed pharma industry, and Hydroxypropyl methylcellulose K4M & K15M was purchased from Vishal chem, Mumbai Lactose, Microcrystalline cellulose, NaHCO3, citric acid, Magnesium Stearate, talc obtained from Central drug house Ltd. analytical grade solvents (Acetonitrile) obtained from Central drug house Ltd.

Table 1: Dissolution method parameter

Parameter	*USP method [14]*	*Developed Method*
Medium	Phosphate buffer (pH6.8-6.9)	0.1 NHCL
Physiological relevance	Intestinal	Gastric
Analysis	HPLC	UV Spectrophotometry
Cost	High	Low
Time	Longer	Rapid

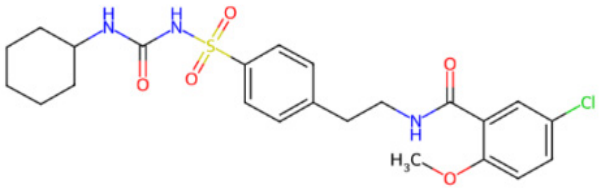

Fig 1: Structure of Glibenclamide[13]

Equipment's

Digital Weighing Balance, Tablet Compression machine, Monsanto Hardness tester, Vernier calliper, Friability apparatus, UV spectrophotometer, FTIR spectrophotometer, Dissolution apparatus, these tools utilized in current study.

Procedure

Solubility

Glibenclamide dissolved in Certain solvents like 0.1N HCl, water, Methanol, Acetonitrile etc. and performed the solubility of drug.

Physical Characterization of Pure drug Glibenclamide:

Fourier-Transform Infrared Spectroscopy: FTIR Spectra of Pure drug Glibenclamide were recorded by using FTIR spectrophotometer (Bruker alpha II).

Determination of Absorption maxima of pure drug Glibenclamide

The Absorption maxima for Glibenclamide in Acetonitrile: water (95:1) and 0.1N HCL was determined by Scanning the Drug Solution from 200nm to 400 nm using UV visible Spectrophotometer having LABINDIA model UV3092 series. And Spectrum wavelength found to be 230.0 nm.

Determination of Calibration curve

Take 10.0 mg of drug in 100 ml volumetric flask. add 60.0 ml of Acetonitrile: water (95:5) and sonicate and make up the volume up to 100ml. prepared 100.0 ppm of stock solution, then serially diluted the stock solution having concentration 2.0 ppm, 4.0ppm, 6.0ppm,8.0ppm,10.0ppm with acetonitrile: water (95:5) and 2.0 ml 0.1NHCl in Each 10 ml flask used as a diluent [1]. & measuring the absorbance 230.0 nm and plot calibration curve was linear in the tested range.

Manufacturing process by direct compression

Using direct compression method, accurately weigh all ingredients like polymer, binder, lubricant, Effervescent agent as per formulation design. Pass all materials like HPMC K4M & K15M, Lactose, Microcrystalline cellulose, NaHCO3, citric acid, through sieve# 40 to ensure uniform

Table 2: Optimized Formulation Batches

Excipients	*F1*	*F2*	*F3*	*F4*	*F5*	*F6*	*F7*	*F8*	*F9*
Glibenclamide	5 mg	5 mg	5 mg	5 mg	5mg	5 mg	5mg	5 mg	5 mg
HPMC k4M	60	70	50	50	60	70	70	50	60
HPMC K15M	60	50	70	70	60	50	50	70	60
NaHco3	25	25	23	24	23	24	23	25	24
Citric acid	6	6	5	7	5	7	5	6	7
Microcrystalline cellulose	15	15	15	15	15	15	15	15	15
Lactose	25	25	25	25	25	25	25	25	25
Talc	2	2	2	2	2	2	2	2	2
Mg stearate	2	2	2	2	2	2	2	2	2
Total	200	200	200	200	200	200	200	200	200

Particle size. Mix Glibenclamide, HPMC K4M and K15M, Lactose, Microcrystalline Cellulose thoroughly. And add Sodium bicarbonate and citric acid and blend gently to avoid premature reaction. add magnesium stearate and talc mix for 2-3 min to avoid overmixing. This prepared mixture was evaluated for Precompression parameters like angle of repose, Bulk density, tapped density, cars index. Compress the final blend using a Tablet compression machine (Mini press II DL, Karnavati Engineering L.T.D). used appropriate punch size (7.14 mm punch size) After the compression of tablet post compression parameters was evaluated [16].

Drug Excipient Compatibility

Drug-excipients compatibility studies were performed in Glibenclamide and selected excipients by preparing the Physical mixture of glibenclamide and individual excipient in 1:1 ratio inn 40 °c for 1 hr to evaluate possible interactions between drug and excipients. That confirm that all excipients used in the formulation are compatible with the drug and can be safety utilized for further formulation development without affecting the stability of the drug.

Application of 3^2Factorial design by Design expert software:

To systematically optimize the formulation variables affecting the performance of the floating tablet of Glibenclamide, a 3^2 full factorial design was employed. This design enables the evaluation of the individual and combined effects of two independent variables at three levels, providing a robust statistical approach for formulation optimization. Design of Experiment, In the present study, two critical formulation variables were selected, This resulted in a total of 9 experimental runs (F1–F9 formulations).

Dependent Variables (Responses)

Quadratic Equation of 3^2 factorial

$$Y = b_0 + b_1X_1 + b_2X_2 + b_{12}X_1X_2 + b_{11}X_{21} + b_2^2X_2^2$$

Where:
Y = response (e.g., drug release, floating lag time, swelling index)
X_1, X_2 = independent variables (e.g., polymer concentration, effervescent agent) β_0 = intercept
β_1, β_2 = linear coefficients β_{12} = interaction coefficient
β_{11}, β_{22} = quadratic coefficients

Evaluation Studies:

Precompression Evaluation:

- *Bulk density*

Bulk density is ratio of given mass of powder and its bulk volume.
Bulk density = M/V0
Where, M = Mass of the powder V0 = bulk volume of the powder.

- *Tapped density*

A known quantity of powder was transferred to a graduated cylinder and volume V0 was noted.
Tapped density = M/Vr Where,

Table 3 : Independent Variables

Independent variables	*Low*	*Medium*	*High*
X1: Polymer Concentration (HPMC)	0.71	1.4	1.055
X2: Gas generating agent concentration	2.6	2.85	3.1

Table 4: Dependent Variables

Dependent Variable	Types
Y1	Floating log time (FLT)
Y2	Total floating time (TFT)
Y3	% Drug release

Table No: 5 Formulation Trials

		Factor 1	Factor 2	Response 1	Response 2
Std	Run	A:HPMC	B:NAHCO3/ Citric Acid	Floating lag time	swellability
		Mg	Mg	Sec	%
8	1	1.055	3.1	2.9	98.12
9	2	1.4	3.1	2.12	99.12
4	3	0.71	2.85	0.38	97.12
1	4	0.71	2.6	0.27	97.1
5	5	1.055	2.85	0.39	98.1
3	6	1.4	2.6	0.28	99.23
6	7	1.4	2.85	0.4	99.23
7	8	0.71	3.1	2.13	97.2
2	9	1.055	2.6	0.3	98.15

Table 6: Organoleptic Properties of Glibenclamide

Parameters	*Results*
Appearance	Crystalline powder
Colour	White
Odour	Odourless

Discussion: Glibenclamide appears as a white to off-white crystalline powder and is odourless in nature. The drug possesses a fine, non-hygroscopic appearance of sulphonyl urea compounds.

Where, M = Mass of the powder, Vr = final tapping volume of the powder

Hausner ratio

Hausner ratio may be calculated using measured values of bulk density and tapped density as follows.
Hausnerratio = Tapped density/Bulk density

Table 7: solubility study

Sr. No	*Solvent*	*Solubility*
1	Water	Insoluble
2	Methanol	Slightly soluble
3	0.1N HCL	Insoluble
4	Acetonitrile	Soluble
5	Ethanol	Slightly soluble

Discussion: Glibenclamide showed very poor solubility in water and 0.1N HCl. the drug was found to be slightly soluble in methanol and good solubility in Acetonitrile.

Compressibility index

The bulk density and tapped density was measured and compressibility index was calculated using the formula
C.I = 100[**(**ρT–ρB**)/**ρB**]**
Where, ρT- Tapped density ρB- Bulk density.

Post Compression Evaluation

- *Appearance*

The colour, shape, and dimension of Prepared tablet formulation was examined.

- *Thickness*

Thickness of Tablet was measured by Vernier calliper, 10 tablets were measured, the thickness to determined average thickness of tablet.

- *Hardness*

hardness of tablet was measured by Hardness tester. 10 tablet was selected and measured the average hardness of tablet in kg/cm2.wv

- *Friability*

6 tablets hold in friability apparatus and set apparatus in

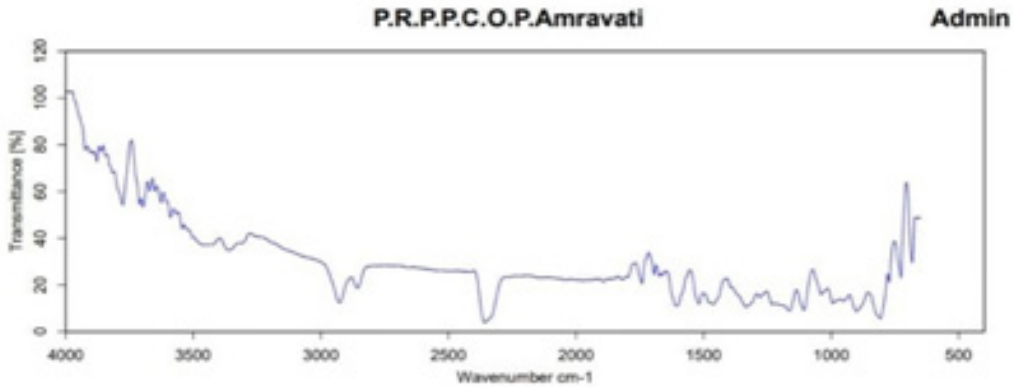

Fig no 2: FTIR of Glibenclamide

Discussion: The FTIR spectrum of glibenclamide showed characteristics peaks at 3360-3310cm-1 (N-H stretching), 2930-2850cm-1(C-H stretching),1750-1660cm-1(C=O stretching), and 1340-1160 cm-1 (S=O stretching). These peaks confirm the presence of sulphonyl urea functional groups and the identity of Glibenclamide

Table 8: Precompression Parameter

Formulation	*Bulk Density (g/cm^3)*	*Tapped Density (g/cm^3)*	*Carr's Index (%)*	*Hausner Ratio*
F1	0.775	0.84	7.7	1.08
F2	0.738	0.775	4.77	1.05
F3	0.738	0.794	7.05	1.07
F4	0.815	0.826	1.33	1.01
F5	0.738	0.756	2.38	1.02
F6	0.72	0.74	2.7	1.02
F7	0.79	0.81	2.46	1.02
F8	0.775	0.79	2.5	1.05
F9	0.70	0.72	2.7	1.02

Discussion: The Precompression parameters of formulations F1-F9 showed satisfactory flow and compressibility. The bulk density values ranged from 0.70 to o.815g/cm3, while tapped density ranged from 0.72 to 0.84 g/cm3, indicating the uniform packing of powder blend. The Carr's index values were found between 1.33% and 7.7% and Hausner ratio values indicate excellent to good flow properties of granule. Among, all batches, F5 showed optimum flow behaviour with Carr's index of 2.38% and Hausner ratio is 1.02, which suggest better compressibility and flowability.

25rpm with 100 revolution per min. The pre-weighed tablet was taken out, and weight after 100 revolutions. Calculate the friability which is not exceed 1%.

- *Weight variation*

test was conducted by weighing 20 tablets individually, calculating the average weight and comparing the individual tablet weight to the Average. the allowed percentage deviation is ±5%. the tablet meets USP test if no more than two tablets are outside the limit and no tablet differs by more than twice the limit [14].

- *Drug Content*

in each formulation was determined by powdering 20 tablets before taking a weight equivalent to one tablet. And this was dissolved in 100.0 ml of Acetonitrile: water (95:1). This sample solution is sonicated to 10 min and filter to Whatman filter paper. And suitably diluted to acetonitrile: water (95:5) and 2.0 ml of 0.1N HCl. before determining the drug concentration on UV spectrophotometer using the same solvent as the blank and measure the absorbance 230.0 nm.

- *Swelling index*

The swelling index of tablets was determined in 0.1NHCl (pH 1.2) at ambient temperature. The tablet was immersed in 100.0 ml of medium. The tablet was removed periodically from dissolution medium. After draining from water by blotting paper, it was measured for weight gain. The swollen weight of tablet was determined at different time intervals for period 12h [1]. The swelling index expressed as a percentage, was calculated from the following formula

Swelling index = weight of tablet at time – initial weight of tablet /

initial weight of tablet x 100

- *In vitro buoyancy studies*

In vitro buoyancy studies were performed for all the formulations batches. Randomly selected tablets from each formulation were kept in 100.0 ml beaker containing 0.1 N HCl at ambient temperature. the time taken for the tablet to surface and float was recorded as the floating lag time (FLT). The Total floating time (TFT) was recorded as the duration

Table 9: Post Compression parameter

Formulation	*Thickness (mm)*	*Hardness (kg/cm^2)*	*Diameter*	*Friability (%)*	*Floating lag Time*	*% Swelling Index*	*% Assay*
					(sec)		
F1	3.22	6	7.10	0.45	2.9	98.12	97.4
F2	3.25	6.5	7.12	0.70	2.12	99.12	99.0
F3	3.26	5.5	7.05	0.65	0.38	97.12	100.0
F4	3.21	7	7.05	0.54	0.27	97.1	98.0
F5	3.20	6.2	7.10	0.65	0.39	98.1	98.4
F6	3.25	6	7.05	0.89	0.28	99.23	96.2
F7	3.24	6.5	7.05	0.75	0.4	99.23	98.4
F8	3.25	6.8	7.03	0.45	2.13	97.2	99.0
F9	3.26	6.0	7.00	0.62	0.3	98.15	101.0

Discussion: The post-compression evaluation of formulation F1-F9 showed acceptable table characteristics within pharmacopeial limits. The thickness ranged form 3.20-3.26 mm, The indicating uniform tablet size, while hardness values from 5.5-7 kg/cm2 conformed adequate mechanical strength. Friability values were below 1%. The Floating lag time of all formulation was satisfactory, indicating effective floating behaviour Swelling index values ranged from 97.1-99.23%, showing good hydration capacity of polymers. Drug assay values were between 96.2-101% conformed uniform drug content. Among all batches F5 showed optimized results with acceptable hardness, low friability, suitable floating time, good swelling index and which indicating it is optimized formulation.

Table 10: % Drug release Data of batch F5

Time(min)	*Absorbance*	*Drug Release %*
30 min	0.070	22.08%
60 min	0.094	31.23 %
120 min	0.137	47.15%
180 min	0.166	58.41%
240 min	0.185	65.15%
300 min	0.206	73.17%
360 min	0.219	78.35%
420min	0.230	82.31%
480 min	0.265	88.26%

of time during which the tablet constantly remains on the surface of medium.[1]

- *In vitro Dissolution studies*

The release rate of Glibenclamide from Sustained release floating tablets was determined using USP II (paddle) dissolution apparatus (DS8000, LABINDIA). The Dissolution test was performed using 900ml of 0.1N HCl as a dissolution medium, maintained at 37 ± 0.5 ° C and stirred at a rate 50.0 rpm. Sample (05ml) were taken from dissolution medium at predetermined time interval for 1 to 8 hr in case of sustained
release floating tablet. Sample were diluted to acetonitrile: water (95:5) and 2.0 ml of 0.1N HCl and taken absorbance of sample at 230.0 nm. Determined % drug release by using the linear equation. sample were replaced with fresh dissolution medium. The percentage cumulative amount of drug dissolved was plotted as a function of time to produce the dissolution profile.

Method Development of Dissolution Study by UV Spectrophotometry

Selection of Apparatus and conditions

Dissolution testing was performed using USP Type II (paddle apparatus) (Lab India DS8000) 0.1NHCl Dissolution Medium by maintaining the 37± 0.5 having 900 ml Dissolution volume constantly stirred at 50.0 rpm with per 60 min 5.0 ml sample was injected.[14]

Development of UV analytical Method

A UV spectrophotometric method was developed for the analysis of the drug using a selected wavelength of 230.0nm. The solvent system comprised acetonitrile and 0.1N HCl. A standard solution was prepared by dissolving 10.0mg of drug in 10.0ml solvent followed by appropriate dilution to obtain

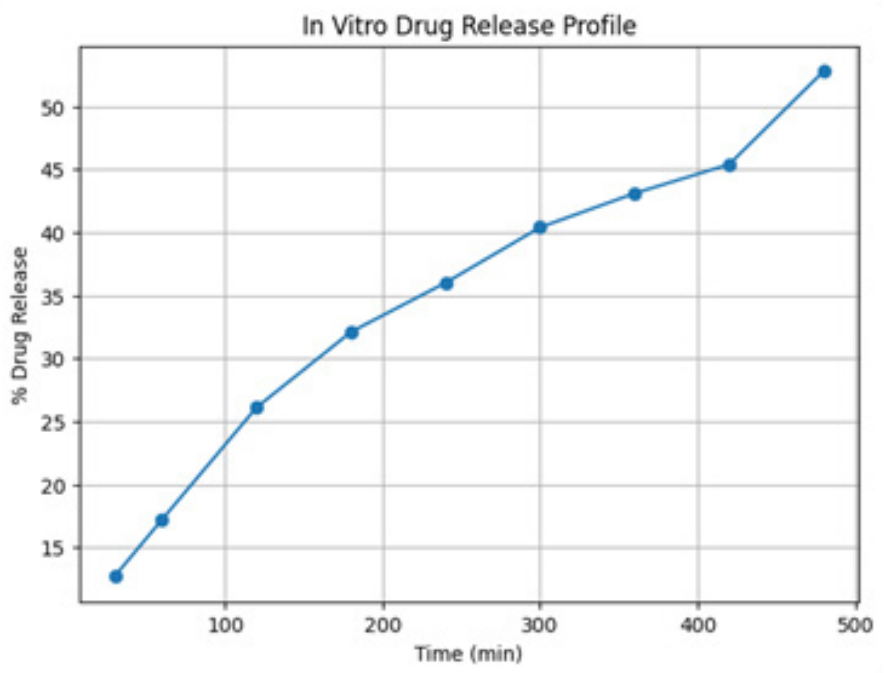

Fig 3: % drug release profile Batch F5

Discussion: The in vitro dissolution profile demonstrates a gradual and sustained increase in drug release over time, indicating effective control of drug release from the formulation. The drug release reached approximately 88% at 480 minutes, suggesting that the formulation is capable of maintaining prolonged drug availability. The absence of any abrupt release in the initial phase indicates that the formulation successfully minimizes burst release, which is desirable for sustained release systems. The smooth and continuous release pattern reflects uniform matrix integrity and consistent drug diffusion. Overall, the release behaviour suggests that the formulation follows a controlled release mechanism, likely governed by diffusion through the polymeric matrix, making it suitable for extended therapeutic action.

Table 11: Evaluation parameters (F5) batch

Evaluation Parameter	*Result*
Thickness	3.56
Hardness	6.5kg/cm2
Diameter	6.96
Floating Lag Time	0.40 sec
Total floating time	15 hr
Swelling index	98.8%
Friability	0.65
% Assay	98.4%
Average weight (±5%)	199.85 mg (within Acceptable limit)
Bulk density	0.588 g/cm3
Tapped Density	0.60 g/cm3
Car's index	2% (Excellent)
Hausner's ratio	1.02 (Excellent)

Discussion: The optimized formulation showed satisfactory precompression characteristics within acceptable limits. The tablet thickness is 3.56mm, diameter is 6.96mm which indicated uniformity in tablet size, while hardness is 6.5 kg/cm2 confirmed good mechanical strength. Friability was found to be 0.65% which is below 1%. The floating lag time was 0.40 sec with total floating time is 15 hr which was excellent floating behaviour. The swelling index is 98.8% indicates good hydration and swelling capacity of HPMC polymer. Drug assayed was found to be 98.4% confirming uniform drug content. The average tablet weight is 199.85 mg was within pharmacopeial limit. Bulk density and tapped density, Hausner ratio which indicated the Excellent flow properties of powder blend. The formulation exhibited satisfactory pharmaceutical characteristics and was considered optimized.

a working concentration of 2.2ppm. the sample solution was prepared by transferring 4.0ml of sample into 10 ml volumetric flask adding 2.0ml of Acetonitrile: water (95:5) and making volume with Acetonitrile: water (95:5) as solvent [14].

Validation of Dissolution study by UV Method

Linearity

Take 10.0mg of drug in 100 ml volumetric flask. add 60.0 ml of Acetonitrile: water (95:5) and sonicate and make up the volume up to 100ml. prepared 100.0 ppm of stock solution, then serially diluted the stock solution having concentration 2.0 ppm, 4.0ppm, 6.0ppm,8.0ppm,10.0ppm with acetonitrile: water (95:5) and 2.0 ml 0.1NHCL in Each 10 ml flask used as a diluent. & measuring the absorbance 230.0 nm and plot calibration curve was linear in the tested range [18].

Accuracy

accuracy is evaluated by recovery of known added drug to different spinking concentration having final concentration of sample.

80% - 4.0 ml dissolution sample, 0.16 ml of working standard and 2 ml of Acetonitrile: water (95:5)

100%- 4.0 ml dissolution sample, 0.2ml of standard and 2 ml of Acetonitrile: water (95:5) 120%- 4.0 ml of dissolution sample, 0.24ml of standard, 2ml of Acetonitrile: water (95:5)% Recovery formula

Ct-Cu/Ca x 100

Where, Ct= Total concentration after spiking Cu= Concentration of sample (un spiked) Ca= Concentration of standard added

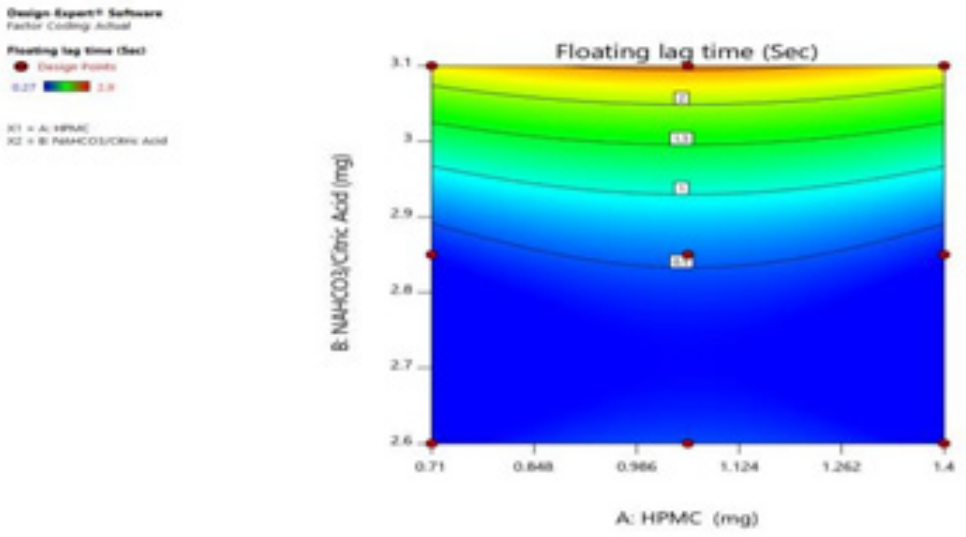

Fig 4: Counter plot showing Effect of NaHCO3 On FLT

Discussion: Effect on Floating Lag Time (FLT): An increase in sodium bicarbonate concentration (X_2) significantly reduced FLT, due to rapid CO_2 generation, which enhances buoyancy. However, increasing polymer concentration (X_1) slightly increased FLT due to higher matrix density

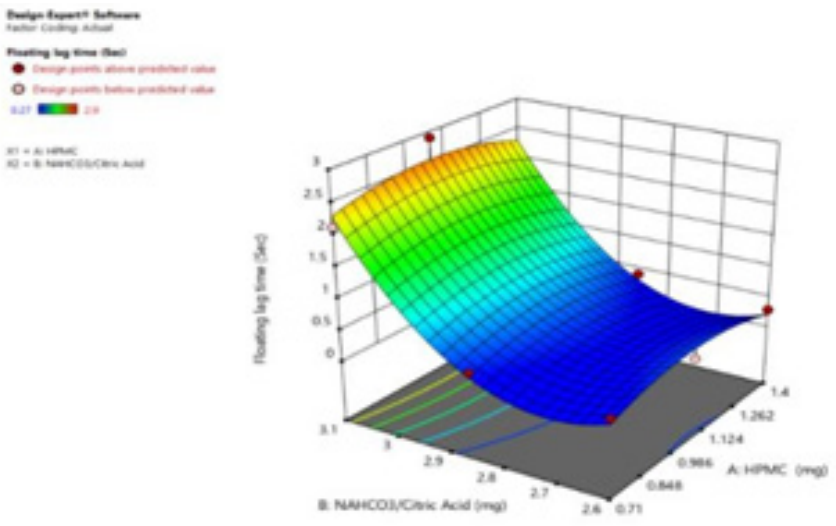

Figure 5: Counter plot showing effect of NaHCO3 and HPMC on FLT

Discussion: Polymer concentration (X_1) showed a positive effect on TFT, as higher polymer levels improve matrix integrity and prolong floating duration. Sodium bicarbonate had a minimal effect on TFT after initial buoyancy was achieved.

Repeatability

Prepared Dissolution sample from same batch(2.2ppm) also Prepared Standard Solution (2.2ppm) Measure absorbance at 230.0nm

%RSD= SD/mean×100

Where, SD= Standard Deviation X = Mean

Limit of Detection

Prepare blank dissolution media and take absorbance at 230nm.

LOD = 3.3 x SD / Slope

Limit of Quantification

prepare blank dissolution media and take absorbance at

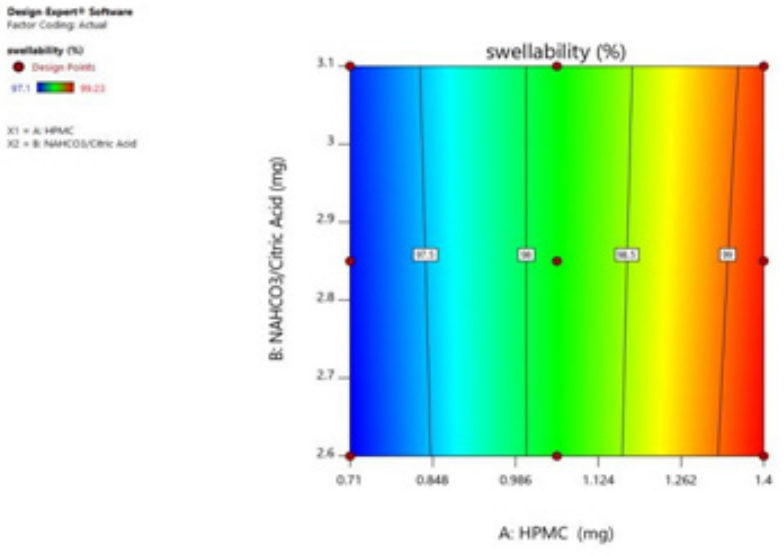

Fig 5: Counter plot showing effect of NaHCO3 and HPMC on swellability

Discussion: Increasing polymer concentration (X_1) resulted in slower drug release, due to formation of a thicker gel barrier Increasing sodium bicarbonate (X_2) slightly enhanced drug release by creating a more porous matrix The optimized formulation showed controlled drug release (~88% in 8 hours), indicating a balance between polymer retardation and matrix porosity.

Table 12: Response 1: Floating lag time

Source	*Sum of Squares*	*df*	*Mean Square*	*F-value*	*p-value*	
Model	8.54	5	1.71	19.80	0.0167	significant
A-HPMC	0.0001	1	0.0001	0.0008	0.9796	
B-NAHCO3/Citric Acid	6.61	1	6.61	76.70	0.0031	
AB	0.0001	1	0.0001	0.0012	0.9750	
A^2	0.1422	1	0.1422	1.65	0.2893	
B^2	1.78	1	1.78	20.64	0.0200	
Residual	0.2587	3	0.0862			
Cor Total	8.80	8				

Factor coding is Coded. Sum of squares is Type III - Partial
The Model F-value of 19.80 implies the model is significant. There is only a 1.67% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case B, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

Table 13: Fit Statistics

Std. Dev.	*0.2937*	*R^2*	*0.9706*
Mean	1.02	Adjusted R^2	0.9216
C.V. %	28.82	Predicted R^2	0.6798
		Adeq Precision	9.9045

The Predicted R^2 of 0.6798 is not as close to the Adjusted R^2 of 0.9216 as one might normally expect; i.e. the difference is more than 0.2. This may indicate a large block effect or a possible problem with your model and/or data. Things to consider are model reduction, response transformation, outliers, etc. All empirical models should be tested by doing confirmation runs. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 9.905 indicates an adequate signal. This model can be used to navigate the design space.

Table 14: Final Equation in Terms of Coded Factors

Floating lag time	=
+0.5678	
+0.0033	A
+1.05	B
-0.0050	AB
-0.2667	A^2
+0.9433	B^2

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

230nm.
LOQ = 10 x SD / Slope

Robustness

Prepare standard and Dissolution sample having concentration 2.2ppm. and small changes introduced in wavelength (±2λmax) in 230nm. And measure absorbance at that wavelength.

Result And Discussion

- Solubility Study
- FTIR of Glibenclamide
- Precompression Evaluation
- Post Compression Evaluation
- Dissolution Studies: (F5 batch)
- Evaluation Parameters for Optimized Batch (F5):
- Optimization of Formulation:
- Counter Plot and 3D surface showing effect of CPP and Response factor
- ANOVA for Quadratic model
- ANOVA for 2FI model
- Floating Lag Time (Quadratic Model)

The quadratic polynomial equation is

Where:
= Floating lag time
= HPMC
= NaHCO/Citric Acid ratio
= Interaction effect between A and B

Table 15: Response 2: swellability

Source	*Sum of Squares*	*df*	*Mean Square*	*F-value*	*p-value*	
Model	6.34	3	2.11	1427.46	< 0.0001	significant
A-HPMC	6.32	1	6.32	4274.76	< 0.0001	
B-NAHCO3/Citric Acid	0.0003	1	0.0003	0.1802	0.6888	
AB	0.0110	1	0.0110	7.45	0.0413	
Residual	0.0074	5	0.0015			
Cor Total	6.34	8				

Factor coding is Coded. Sum of squares is Type III - Partial
The Model F-value of 1427.46 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A, AB are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

Table 16: Fit Statistics

Std. Dev.	*0.0385*	*R^2*	*0.9988*
Mean	98.15	Adjusted R^2	0.9981
C.V. %	0.0392	Predicted R^2	0.9962
		Adeq Precision	84.1706

The Predicted R^2 of 0.9962 is in reasonable agreement with the Adjusted R^2 of 0.9981; i.e. the difference is less than 0.2.
Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 84.171 indicates an adequate signal. This model can be used to navigate the design space.

Table 16: Final Equation in Terms of Coded Factors

swellability	=
+98.15	
+1.03	A
-0.0067	B
-0.0525	AB

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

Table 17: Calibration curve data

Concentration(ppm)	*Absorbance*
2	0.058
4	0.11
6	0.155
8	0.205
10	0250

Interpretation

- Positive coefficient of (+1.05) indicates increase in NaHCO/ Citric Acid increases floating lag time.
- Negative coefficient of indicates curvature with decreasing trend at higher HPMC level.
- Positive coefficient of shows strong quadratic effect of effervescent agents.
- Interaction term is very small and insignificant.

Swellability (2FI Model)

The 2-Factor Interaction (2FI) equation is

Where:
= Swellability
= HPMC
= NaHCO/Citric Acid ratio
= Interaction effect between A and B

Interpretation

- Positive coefficient of (+1.03) indicates HPMC significantly increases swellability.
- has negligible negative effect.
- Negative interaction coefficient () suggests combined increase of A and B slightly decreases swellability.

General Polynomial Forms

Quadratic Model

- *2FI Model*

These equations can be used for prediction and optimization of formulation variables within the design space.

FTIR of Formulation

Validation Parameters of Developed Dissolution UV analysis method

- *Spectrum of Glibenclamide*

Linearity
- Accuracy
- Repeatability
- LOD and LOQ
- Robustness:
- Risk Analysis Table for Optimized Batch (F5)

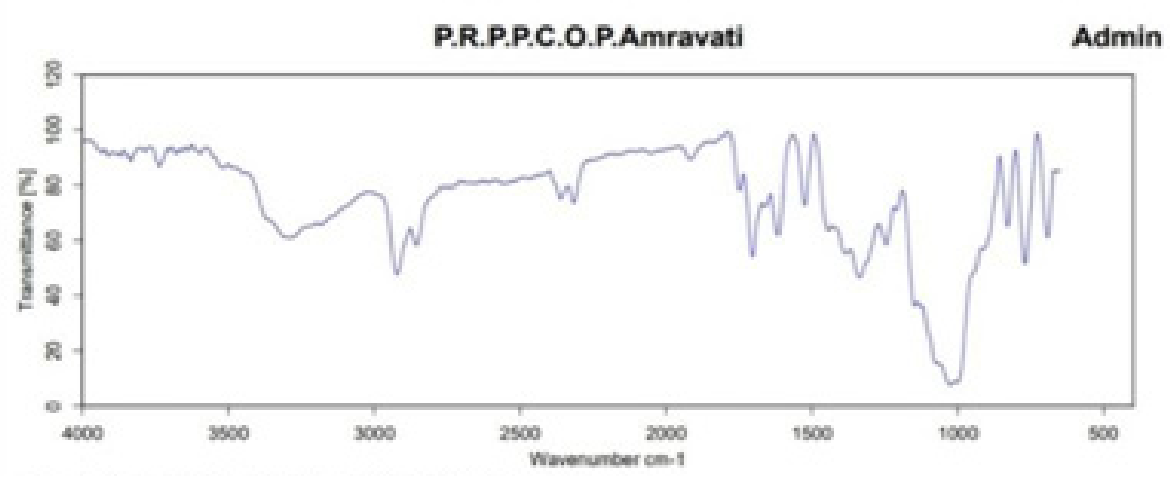

Fig No.6 FTIR of Formulation

Discussion: The Spectrum of Optimized formulation showed characteristics peaks corresponding to Glibenclamide without significant shifting of major peaks. The characteristics peaks observed for N-H stretching, C=O stretching, and S=O stretching confirmed the presence and integrity of the drug in the formulation. The spectra of drug and excipients were found to be compatible, indicating the absence of any significant drug excipient interaction. Thus, the FTIR study confirmed the stability and compatibility of formulation components.

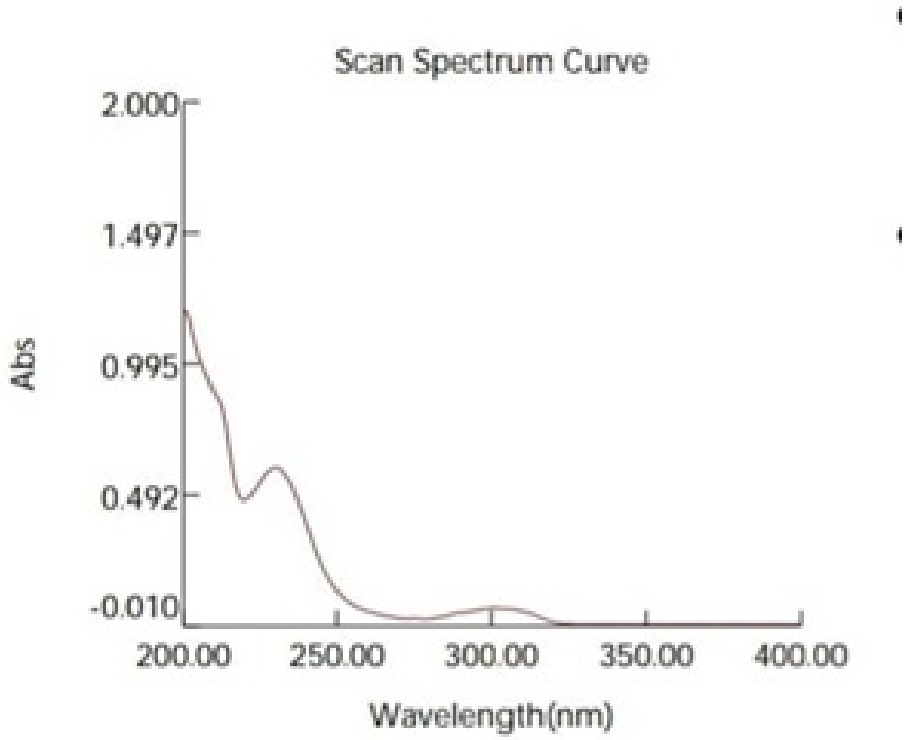

Figure No. 7 Spectrum of Glibenclamide

Discussion: The absorption maximum (λ-max) for Glibenclamide in Acetonitrile: Water (95:1) & 0.1NHCL was determined by scanning the drug solution from 200 nm to 400 nm using a UV-Visible Spectrophotometer. The spectrum curve of clotrimazole constructed at 230.00 nm.

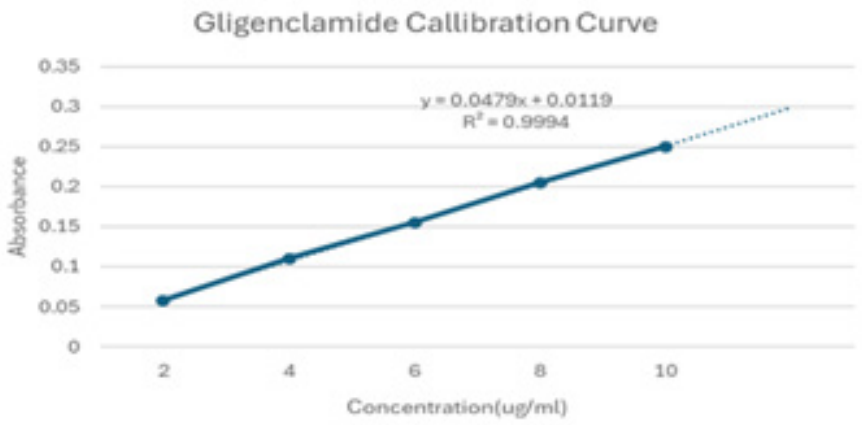

Fig no 8: Calibration curve of Glibenclamide

Discussion: Linearity range of Glibenclamide 2-10 ppm in Acetonitrile: water (95:5) as a solvent and the R^2 was found to be 0.9994 which is within the acceptable limits.

Table 18: % recovery of Glibenclamide Tablet

Level	*Volume of sample solution(ml)*	*Volume of standard(ml)*	*Absorbance*	*%Recovery*
	4.0	0.16	0.302	98.7%
80%	4.0	0.16	0.304	100.0%
	4.0	0.16	0.306	102.8%
	4.0	0.2	0.322	98.3%
100%	4.0	0.2	0.324	100.0%
	4.0	0.2	0.326	101.4%
	4.0	0.24	0.344	98.5%
120%	4.0	0.24	0.348	100%
	4.0	0.24	0.346	101.0%

Discussion: as per ICH guidelines, accuracy is evaluated by recovery studies at 80%, 100%, 120% level by spiking standard drug into the sample.

Table 19: Repeatability of Glibenclamide tablet

Sr. No	*Standard Absorbance*	*Sample Absorbance*
1	0.245	0.116
2	0.249	0.117
3	0.251	0.115
4	0.250	0.119
5	0.247	0.117
6	0.249	0.118
%RSD	0.17%	1.5%

Discussion: as per ICH guidelines, repeatability is expressed as % RSD (relative standard deviation) and acceptance criteria is generally %RSD $\leq$ 2%. It is the repeatable measurement of sample solution and standard under the specified condition.

Table 20: Blank Reading

Sr. No	*Blank Absorbance*
1	0.001
2	0.002
3	0.003
4	0.002
5	0.006
6	0.005
Standard Deviation	0.00194

Table 21 : LOD and LOQ

Parameters	*Result*
LOD (ug/ml)	0.133
LOQ (ug/ml)	0.40

Discussion: Limit of detection and limit of Quantification of sample solution was found to be 0.133 ug/ml and 0.40 ug/ml within acceptable limit.

Table 22: Robustness

Wave length(nm)	Absorbance	mean	SD	%RSD
	0.088			
Actual 230.0	0.086	0.087	0.0010	1.15%
	0.087			
	0.089			
229.0 (-1)	0.087	0.0887	0.0015	1.70%
	0.090			
231(+1)	0.087			
	0.088	0.088	0.0010	1.14%
	0.089			

Discussion: % RSD was found to be within acceptable limit %RSD$\leq$2%.

Table 23: Validation parameters of Dissolution UV method as per ICH

Sr. no	*Parameters*	*Acceptance Criteria (ICH)*	*Result Obtained*	*Conclusion*
1	Linearity	$R^2 \geq 0.999$	0.9994	Complies
2	Accuracy	98%-102%	98%-102%	Complies
3	Repeatability	%RSD≤2%	0.17%-1.5%	Complies
4	LOD	-	0.133ug/ml	Complies
5	LOQ	-	0.40 ug/ml	Complies
6	Robustness	%RSD≤2%	Within limit	Complies

Quality Risk analysis: Quality Risk analysis of Sustained release floating tablet performed based on the to identifying Critical Quality attributes, and identifying risks factors.
Critical Quality Attributes:
Floating lag time: should be low (>1 min)
Total Floating Time- should be high (up to 20hr)
Swelling index (should be optimum/high) Identify risk Factors: (Critical material attributes):
Polymer concentration: e.g HPMC K4M & HPMC K15M
Effervescent agent: e.g NaHco3, citric acid
Hardness: 6-7 kgcm2.
Steps:
To apply FMEA (failure mode effect analysis)
Assign Score (1-10) based on severity, occurrence, and detectability.
To Interpret the RPN number and range of Formulated batch based on practical observations [33]
Risk analysis Tablet of Formulated batch:

Table 24: Risk analysis Table

Batches	*S*	*L*	*D*	*RPN*
Batch 1	5	1	5	25
Batch2	5	1	4	20
Batch3	5	2	4	40
Batch4	3	2	3	18
Batch5	4	4	1	16
Batch 6	4	4	2	32
Batch7	3	3	3	27
Batch8	2	3	3	18
Batch9	2	4	1	8
Batch10	2	4	3	24
Batch 11	4	2	3	24
Batch 12	2	5	1	10

Discussion: The Risk analysis demonstrates that the concentration of effervescent agent significantly influences the floating lag time, where higher concentrations result in rapid CO_2 generation and reduced lag time. In contrast, polymer concentration plays a crucial role in controlling total floating time and swelling behaviour, with higher polymer levels enhancing gel strength, prolonging buoyancy, and increasing swelling index. An optimal balance between effervescent agent and polymer is essential to achieve immediate buoyancy with prolonged gastric retention. Based on the results, Batch 2 showed minimum floating lag time, while Batch Batch 4–6 exhibited extended total floating time due to higher polymer concentration. If lag time increases or Total floating time decrease then severity high and RPN increase.

Table 25: Risk analysis Table

Batches	*S*	*L*	*D*	*RPN*
Batch 1	4	2	4	32
Batch2	3	3	3	27
Batch3	3	2	3	18
Batch4	2	3	2	12
Batch5	**2**	**1**	2	4
Batch 6	3	2	3	18
Batch7	3	4	3	36
Batch8	2	3	2	12
Batch9	3	2	2	12

Discussion: The risk analysis indicates that both polymer concentration and effervescent agent significantly influence the floating behaviour of the formulation. Excessive effervescent agent leads to rapid CO_2 generation, compromising matrix integrity and increasing RPN, whereas insufficient levels delay floating. Similarly, high polymer concentration enhances swelling and floating duration but may retard gas diffusion, increasing variability. Batch 5 demonstrated the lowest RPN, indicating an optimal balance between swelling, floating lag time, and total floating duration. Therefore, a controlled ratio of polymer to effervescent agent is critical for achieving a stable and efficient floating drug delivery system. The RPN-based risk assessment confirms that formulation optimization is achieved when severity, occurrence, and detection are minimized, resulting in a robust and reproducible floating drug delivery system.

Conclusion

The Present study successfully developed and optimized a sustained release floating tablet of glibenclamide using a hydrophilic polymer matrix system. The optimized formulation showed satisfactory physiochemical properties, rapid floating behaviour, prolonged gastric retention, and controlled drug release over 8 hr. Drug release followed a non-Fickian mechanism involving diffusion and polymer erosion. Factorial design and FMEA studies confirmed the significant effect of polymer and effervescent agent concentration on tablet performance, with Batch F5 showing the lowest RPN value, overall, the developed gastroretentive system improved sustained drug release, patient compliance in diabetes mellitus treatment.

Acknowledgement

Authors are thankful to the Management of P. R. Pote Patil College of Pharmacy Amravati for their support and encouragement throughout this research work.

References

1. Essa EA, Elkotb FE, Zin Eldin EE, El Maghraby GM. Development and evaluation of glibenclamide floating tablet with optimum release. J Drug Deliv Sci Technol. 2015;27:28-36.
2. Lou J, Duan H, Qin Q, Teng Z, Gan F, Zhou X, et al. Advances in oral drug delivery systems: challenges and opportunities. Pharmaceutics. 2023;15(2):484. doi:10.3390/pharmaceutics15020484.
3. Maurya VB. A review on gastroretentive drug delivery systems. Int J Pharm Pharm Sci. 2025;7(1):375-380.
4. Modekar SD, et al. A review on gastro retentive drug delivery: strategies for prolonged gastric retention. World J Pharm Sci Res. 2025;4(2):1161-1176.
5. Sarawade A, Ratnaparkhi MP, Chaudhari S. Floating drug delivery system: an overview. Int J Res Dev Pharm Life Sci. 2014;3(5):1106-1115.
6. Vasave VS. A review on floating drug delivery system. World J Pharm Res. 2023;12(2):641-669.
7. Omidian H. Gastroretentive drug delivery systems: a holy grail in oral drug delivery. Sci Direct. 2025.
8. Trineshsai J. A review on floating drug delivery system. Int J Zool Environ Life Sci. 2025;2(2):21-25. doi:10.70604/ijzels.v2i2.56.
9. Cave G, Nicholson SJ. Glyburide composition. United States patent US 6,830,760 B2. 2004 Dec 14.
10. Cazedey ECL, Salgado HRN. Development and validation of UV spectrophotometric method for orbifloxacin assay and dissolution studies. Braz J Pharm Sci. 2011;47(3).
11. Vinchurkar K, Sainy J, Khan MA, Mane S, Mishra DK, Dixit P. Features and facts of a gastroretentive drug delivery system-a review. Turk J Pharm Sci. 2022;19(4):476-487. doi:10.4274/tjps.galenos.2021.4495.
12. Pawar VK, Kansal S, Garg G, Awasthi R, Singodia D, Kulkarni GT. Gastroretentive dosage forms: a review with special emphasis on floating drug delivery systems. Drug Deliv. 2011;18(2):97-110. doi:10.3109/10717544.2010.520354.
13. Bhuyar SR, Auti MM, Bhise SA, Radal PS, Gore PS, Sapkal SB, et al. Innovations and advancements in floating tablet drug delivery systems: a comprehensive review. Pharm Pharmacol Int J. 2024;12(5).
14. United States Pharmacopeia 34-National Formulary 29. Revision bulletin. Official October 1, 2010. Rockville (MD): United States Pharmacopeial Convention; 2010.
15. Aulton ME, Taylor KMG. Aulton's pharmaceutics: the design and manufacture of medicines. 5th ed. Edinburgh: Elsevier; 2018.
16. Rowe RC, Sheskey PJ, Quinn ME, editors. Handbook of pharmaceutical excipients. 7th ed. London: Pharmaceutical Press; 2012.
17. Senjoti FG, Mahmood S, Jaffri JM, Mandal UK. Design and in-vitro evaluation of sustained release floating tablets of metformin HCl based on effervescence and swelling. Iran J Pharm Res. 2016;15(1):53-70.
18. Gupta C, Sahu GK, Parashar AK, Singh K, Bukke SPN, Udom GJ. Novel curcumin floating tablets for spatial delivery in peptic ulcer. Biomed Res Int. 2025;2025:6622146. doi:10.1155/bmri/6622146.
19. Selva Vignesh M, Selvi G, Nirmal P. Development and evaluation of a floating drug delivery system for the sustained release of vildagliptin and metformin in combination therapy. Int J Sci Res Technol. 2025;2(6):457.
20. Sathvik T, Tyagi Y, Venkatesh, Shilpa, Mamtha, Patil PB, et al. Formulation and evaluation of atenolol floating tablets using polymers. Asian J Pharm Technol. 2025;15(3):217-225. doi:10.52711/2231-5713.2025.00033.
21. Kulkarni GS, Chaudhary PP, Swamy S. Formulation and evaluation of sustained release floating tablets of an antihypertensive diltiazem. Int J Pharm Sci Nanotechnol. 2017;10(5):3805-3811. doi:10.37285/ijpsn.2017.10.5.5.
22. Kamere K, Gopalakrishna SV, Subbareddy GV. Optimization of repaglinide controlled release floating tablet. Res J Pharm Technol. 2021;14(1):109-114. doi:10.5958/0974-360X.2021.00020.2.
23. Chowdary KPR, Hussainya SA. Formulation and evaluation of floating tablets of gliclazide employing HPMC and Carbopol. Int J Chem Sci. 2012;10(3):121.
24. Albadry AA, Ali WK, Al-Saady FA. Formulation and evaluation of prochlorperazine maleate sustained release floating tablet. Int J Pharm Pharm Sci. 2017;9(2).
25. Prajapati PH, Nakum VV, Patel CN. Formulation and evaluation of floating matrix tablet of stavudine. Int J Pharm Sci Rev Res. 2012;2(2):83-89.
26. Nigusse B, Gebre-Mariam T, Belete A. Design, development and optimization of sustained release floating, bioadhesive and swellable matrix tablet of ranitidine hydrochloride. PLoS One. 2021;16(6):e0253391. doi:10.1371/journal.pone.0253391.
27. World Health Organization. The International

Pharmacopoeia. 6th ed. Geneva: World Health Organization; 2016. Glibenclamide (Glibenclamidum).
28. Nayak K, et al. Formulation and evaluation of sustained release matrix tablets of glibenclamide. World J Pharm Res. 2016;5(11):974-988. doi:10.20959/wjpr201611-723.
29. Elkotb FE, et al. Development and evaluation of glibenclamide floating tablet with optimum release. J Drug Deliv Sci Technol. 2015;28:28-36. doi:10.1016/j.jddst.2015.04.002.
30. Kharia AA, Hiremath SN, Singhai AK, Omray LK, Jain SK. Design and optimization of floating drug delivery system of acyclovir. Indian J Pharm Sci. 2010;72(5):599-606.
31. Rahamathulla M, Alshahrani SM, Al Saqr A, Alshetaili A, Shakeel F. Effervescent floating matrix tablets of a novel anti-cancer drug neratinib for breast cancer treatment. J Drug Deliv Sci Technol. 2021;66:102788. doi:10.1016/j.jddst.2021.102788.
32. Sharma OP, Patel V, Mehta T. Quality risk management in pharmaceutical development using failure mode and effects analysis. Int J Pharm Sci Rev Res. 2010;3(1):27-35.

How to cite this article: Welankiwar A, Sitre V, Ruikar D, Bonde D. Development And Characterization of Floating Sustained-Release Tablets of an Anti-Diabetic Drug. Journal of Applied Pharmaceutical Sciences and Research. 2026; 9(2):84-98 Doi : 10.31069/japsr.v9i2.08