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Mathematical Modeling of Pulsatile Blood Flow with Microbial Suspensions Under Magnetic Influence

Dr.Niyaz Begum

Associate professor

Government Women's First Grade College Jewargi Colony Kalaburagi.

niyazplus@gmail.com

Dr. Syeda Rasheeda Parveen

Assistant professor

Government First Grade College for Women Raichur

pmsmadni@gmail.com

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Abstract

The research evaluates pulsatile blood flow mathematical modeling while applying both microbial suspensions and magnetic field conditions. A model uses blood as an incompressible Newtonian fluid combined with microbial suspensions to develop simulations matching real medical scenarios where microorganisms exist in bloodstream conditions. Blood flow models incorporate physiological pulses due to their vital role in healthcare but include magnetic features to examine how this force influences dynamic behaviors which healthcare applications utilize through targeted delivery systems and magnetic resonance capabilities. The model employs Navier-Stokes equations alongside microbial transport dynamics to evaluate parameters consisting of velocity profiles and pressure gradients and microbial distribution patterns across different magnetic field strengths. Analysis through numerical methods reveals how magnetic forces influence stability, energy use and microbial organization in a simulated system. The study demonstrates how magnetic fields modify flow patterns to create controlled bacterial suspension

transport systems and reduce turbulence during selected operating configurations. Research findings show utility potential for biomedical developments focusing on magnetically steered drug methods along with microbial disease solutions and blood pressure analyses. The analysis reveals parameters which improve therapeutic effects through magnetic field optimization without harming blood flow integrity. The work establishes a practical connection between mathematical modeling and medical technology application to support experimental research and theoretical developments.

Keywords: Pulsatile blood flow, microbial suspensions, magnetic influence, hemodynamics, mathematical modeling, biomedical applications.

Introduction

Studying pulsatile blood flow patterns in biological systems maintains broad interest because it directly supports the analysis of intricate biological functions and advanced medical technology developments. According to specific conditions blood demonstrates non-Newtonian fluid behavior while showing pulsatile patterns during cardiovascular system transit. Cardiac rhythmic contractions generate pulsatile flow patterns which produce oscillating velocity changes and pressure variations. The accurate evaluation of pulsatile blood flow patterns remains essential because blood encounters multiple external influences including microbial suspensions and magnetic fields. The bloodstream contains microbial suspensions both as part of natural human microbiome processes and for deliberate medical applications such as therapeutic microbes and targeted pharmaceutical delivery. The physical character and flow patterns of blood undergo fundamental changes due to microorganisms which modify its operational dynamics across physiological health conditions and disease states. The study of how magnetic fields affect blood flow generates increasing interest for biomedical engineering applications and therapeutic interventions. Applied magnetic fields serve vital roles in targeting delivery systems and MRI diagnostic methods and magneto-hemodynamic testing to manage blood stream parameters. The combination of magnetic fields with microbial suspensions allows for improved therapeutic delivery by steering microbial agents alongside therapeutic particles toward precise body regions. The theoretical and experimental evaluation of blood flow with microbial agents under magnetic field interaction presents an unresolved challenge despite its industrial significance. A holistic

mathematical model needs development to analyze pulsatile blood flow coordination with microbial suspensions alongside magnetic force influence. Analysis starts from Navier-Stokes equations to represent fluid behavior while introducing additional elements that represent microbial motion and magnetic field influence. Solving these equations through numerical methods allows researchers to examine essential parameters regarding velocity distributions and both microbial transport behavior and pressure distribution patterns across different magnetic field values. The model combines real physiological conditions together with experimental validation to explain the impact magnetic forces have on both pulse-based blood flow dynamics and transportation pathways of microorganisms. This study yields vital applications for biomedical outcomes through new generations of magnetically guided therapy systems combined with improved magneto-hemodynamic imaging diagnostics along with advanced knowledge of microbial motion in fluid environments. This research produces valuable outcomes which enhance biofluid mechanics understanding by providing an analysis framework for multifaceted biomedical sciences systems. The study connects fundamental theoretical approaches to practical usage by establishing guidelines for upcoming developments in magnetic regulation of biological systems.

Related Work

M. H. Alruyshid, et al (2021) The paper considers the significance of the modeling and control problems solving for the pressure swing adsorption process in high-purity hydrogen production systems. The problem of mathematical models package development for hydrogen adsorption process by activated carbon is investigated. The state-of-art is analyzed and challenges are identified. The field of blood flow research has seen an increasing importance of studying microbial suspensions because of their application potential for infection management and axis-targeted drug transportation and microbiome understanding. A mixture of either fungal or bacterial agents dispersed in blood specimens alters how the fluid behaves rheologically. Research investigations present mathematical models that examine how microbial elements affect blood flow patterns during different medical procedures.

M. Scott, et al (2021) The collection of 3D cell tracking data from live images of micro-tissues is a recent innovation made possible due to advances in imaging techniques. As such there is increased interest in studying cell motility in 3D in vitro model systems but a lack of rigorous

methodology for analysing the resulting data sets. One such instance of the use of these in vitro models is in the study of cancerous tumours. The complex interactions between host immune systems and microbial agents modify blood flow properties by shaping both microbial behavior and the motion of microorganisms within flowing blood. Scientific interest in how external magnetic fields affect biological fluids particularly blood has expanded rapidly within magnetohydrodynamics (MHD) and biomedical engineering. Researchers apply magnetic fields to manipulate fluids in multiple applications which include medical imaging tools alongside designing drug delivery solutions using magnetically responsive components.

I. Dorosh, et al (2024) The paper investigates mathematical models of the balance of carotenoid accumulation and biomass of the microalgae Desmodesmus armatus population under the multidirectional action of substrates, in particular, activating, which promotes biomass growth, and inhibiting, which suppresses biomass accumulation but accelerates carotenoid biosynthesis. impact of magnetic field actions on microbial suspensions but exactly how these interactions function under pulsatile flows requires further investigation. The current need emerges for an integrated mathematical framework to study pulsatile blood flow together with microbial transport and magnetic influence since separate research made excellent progress. This computational approach provides useful knowledge for numerous biomedical uses ranging from drug delivery with magnets to microbial treatment options and blood flow analysis of diseases. The assessment demonstrates that interdisciplinary research in simulation modeling of complex systems needs to continue because joint systematic methods produce valuable findings.

K. -K. Chen, et al (2023) Heterogeneous medium enhanced angiogr- ams are key diagnostic tools in clinical practice; the associated hemodynamic information is crucial for diagnosing cardiovascular diseases. However, the dynamics of such medium in physiological blood flow are poorly understood. Herein, we report a previously unnoticed dispersion pattern, which is a universal phenomenon, of a medium in pulsatile blood flow. The research literature evaluating pulsatile blood flow and magnetic effects on microbial suspensions remains limited because few investigators have developed integrated models which encompass all elements. The successful integration of fluid flow modeling with microbial dynamics and magnetic force modeling has been limited by their concurrent multiplicity. Research studies from recent years have attempted to

model magnetic field effects on suspensions' movement in non-pulsatile flows but these models typically dismiss pulsatile flow's time-variability.

K. -K. Chen, et al (2021) Digital subtraction angiography (DSA) is the gold standard for diagnosing vascular diseases. Much attention had been attracted on estimating blood flow velocity from DSA data, and many techniques to compute the mean flow velocity had been proposed. In this paper, we present a physical model that demonstrates how the pulsatile flow can affect the dispersion of the contrast medium delivered into the blood vessel.

Methodology

Pulsatile blood flow models with microbial suspensions subject to a magnetic environment employs mathematical methods which unite fluid dynamics with microbiology and present magnetic field concepts to mimic blood cell behavior. Blood flow demonstrates remarkable non-Newtonian fluid characteristics due to microbial particles while pulsatile behavior patterns emerge from time-dependent sinusoidal representations matching cardiac rhythmic activity. The computational approach utilizes Navier-Stokes equations for blood flow dynamics modelling while combining Stokes' law and drag forces with magnetic field influence on microbial particle movement. The Lorentz force equation controls magnetic forces which shift particle movement patterns to modify the entire flow system behavior. The model uses kinetic theory to evaluate blood-microorganism interactions through analysis of the resistance effect from blood viscosity and flow rate. The model examines microbial suspension behaviors across multiple physiological and magnetic field settings as it helps scientists understand disease pathways and drug transport and diagnostic applications within bloodstream environments. This methodology enables simulation of multiple situations which creates a powerful tool for biomedical investigations focusing on microbial movement and bloodstream response to magnetic fields.

Mathematical Formulation

The study aims to develop a mathematical model for pulsatile blood flow with microbial suspensions under magnetic influence, addressing a critical gap in biomedical fluid dynamics. Blood flow in the human body exhibits pulsatile behavior due to rhythmic cardiac contractions,

and its interaction with microbial suspensions introduces complex non-Newtonian fluid characteristics. Additionally, the application of magnetic fields alters blood viscosity, flow stability, and microbial transport mechanisms, which are essential for advancements in targeted drug delivery, microbial therapy, and medical imaging technologies.

The challenge lies in accurately modeling the interplay between fluid dynamics, microbial motion, and magnetic forces. Existing models either focus on pulsatile flow or microbial suspensions in isolation, neglecting their combined effect under varying magnetic intensities. This research integrates Navier-Stokes equations, microbial transport dynamics, and Lorentz force principles to evaluate parameters like velocity profiles, pressure gradients, and microbial distribution. The study aims to optimize magnetic field conditions to enhance therapeutic applications without compromising blood flow integrity, providing a computational framework for experimental validation and biomedical engineering advancements.

1. **Blood Flow Dynamics:** The blood flow is treated as a non-Newtonian fluid due to the presence of suspended microbial particles. The most common approach to modeling blood flow is the **Navier-Stokes equations** for incompressible, viscous flow:

$$\rho\left(\frac{\partial v}{\partial t} + v \cdot \nabla v\right) = -\nabla p + \mu\nabla^2 v + F$$

Where:

- ρ is the density of the blood,
- v is the velocity field,
- p is the pressure,
- μ is the dynamic viscosity,
- F is the external force (including magnetic forces acting on microbial particles).

Pulsatile Flow: Blood flow exhibits a pulsatile nature, which can be modeled using a time-dependent function such as a sinusoidal waveform. The pulsatile flow can be modeled as:

$$Q(t) = Q_0(1 + \alpha \sin(\omega t))$$

Where:

- Q(t) is the volumetric flow rate at time t,
- Q0 is the mean flow rate,
- α is the amplitude of pulsation,
- ω is the angular frequency (related to the heart rate).

Microbial Suspension Dynamics: Microbial particles suspended in blood can be modeled using the **Bingham plastic model** for non-Newtonian fluids or by incorporating the **Stokes' law** for sedimentation in the presence of a magnetic field. The motion of microbial particles under magnetic influence can be described by the equation:

$$\frac{dv}{dt} = \frac{\tau}{m}\left(F_{\text{drag}} + F_{\text{magnetic}}\right)$$

Where:

- vm is the velocity of microbial particles,
- τ is the relaxation time of the microbial particles,
- $F_{\text{drag}} = 6\pi\mu r v$ is the drag force (with r being the radius of the particles),
- $F_{\text{magnetic}} = \nabla(m \cdot \boldsymbol{B})$ is the magnetic force (with m being the magnetic moment and B the magnetic field).

Magnetic Field Influence: The magnetic field influences the motion of the microbial particles in the blood flow. The interaction between the field and the microbial particles can be modeled using the **Lorentz force** equation:

$$FLrnz = qE + v \times B$$

Where:

- q is the charge of the microbial particles (assumed to be magnetically susceptible),

- E is the electric field (if applicable),
- B is the magnetic field.

This equation allows the modeling of how the magnetic field affects the trajectory and velocity of suspended microorganisms.

Blood and Microbial Interaction: The interaction between blood flow and microbial particles is modeled using the **kinetic theory of suspensions**. The collision dynamics of particles in the fluid can be included through a term that describes the drag coefficient Cd, which depends on the relative velocity between the particle and the blood flow:

$$C_d = \mathrm{Re}^{24}\left(1 + 0.15\,\mathrm{Re}^{0.687}\right)$$

Where:

- Re is the Reynolds number, given by

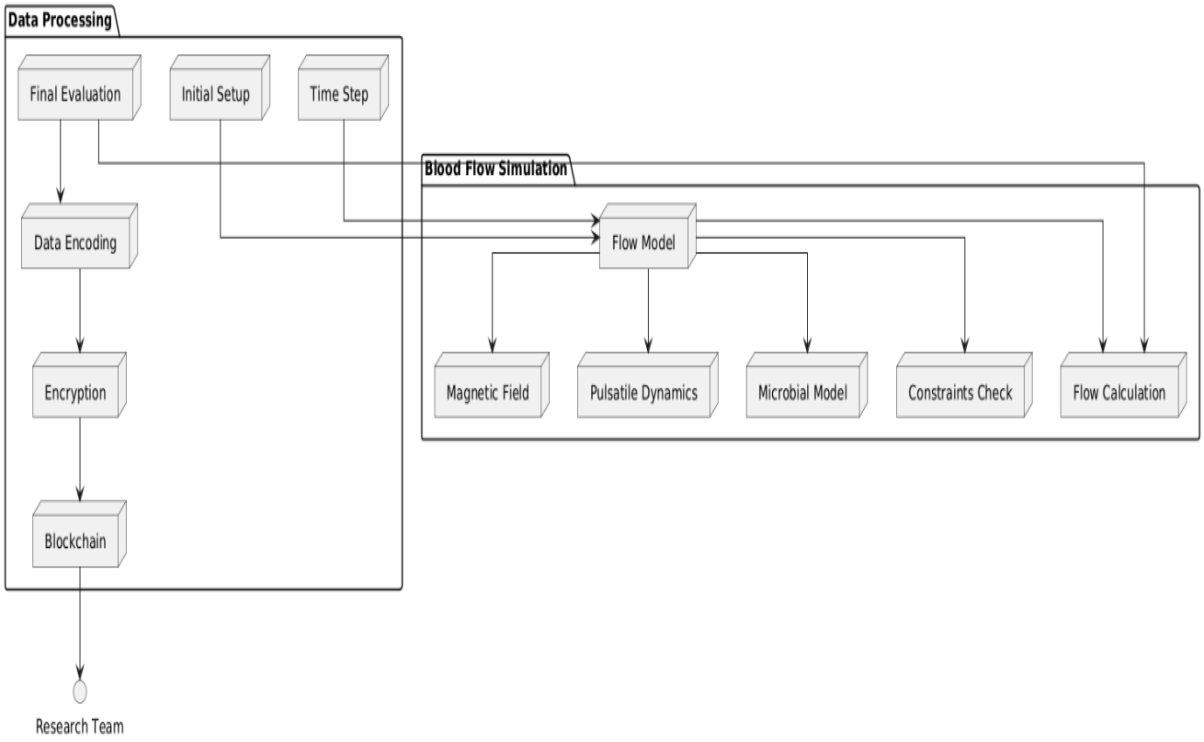
$$\mathrm{Re} = \frac{\mu}{\rho v D}$$

- D is the particle diameter.

This equation adjusts the resistance felt by the particles as they move through the blood flow.

The mathematical modeling technique unites fluid dynamics principles and biological system conduct together with external magnetic field effects to model pulsatile blood flow antagonized by microbial suspensions. The outlined fundamental equations serve as the groundwork to analyze intricate physical interactions which now guide computational modeling and experimental testing forward.

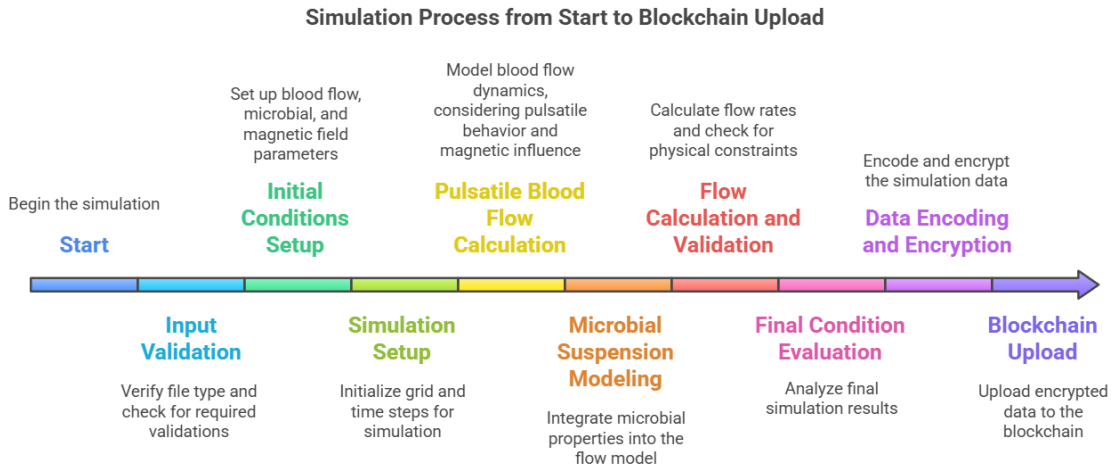
System Architecture



The system infrastructure of Pulsatile Blood Flow Mathematical Modeling with Microbial Suspensions Under Magnetic Influence incorporates simulation capabilities for blood flow and magnetic field interactions with microbial suspensions. The Blood Flow Simulation function and Data Processing procedures make up the fundamental units of this system. The Blood Flow Simulation involves several models: Three essential models reside within the system architecture: the Flow Model performs blood flow simulation and the Microbial Model regulates microbial suspension behavior and the Magnetic Field affects both flow and microbial movement. The simulation depends upon dual models: Pulsatile Dynamics evaluates blood flow pulsations yet Flow Calculation along with Constraints Check performs physical constraint validation then flow rate calculations. The initial setup in the Data Processing stage delivers simulation input data which is followed by sequential time step advancements in the simulation. The encryption process takes place following simulation completion when the results undergo evaluation before secure encoding and encryption. The encrypted simulation data receives Blockchain storage that enables secure sharing with the research team. The established architecture allows researchers to perform efficient

secure scalable analysis of pulsatile blood flow dynamics when studied with microbial suspensions exposed to magnetic fields.

Flowchart



Algorithm

Input: DataFile F, InitialConditions C.
Output: SimulatedBloodFlow S, FinalConditions FC.
1: if (File is of the correct file type) then
2: if (File passes required checks) then
3: fileHash UploadFileToIPFS(F);
4: else
5: File is not compliant;
6: end if
7: else
8: File is not of the correct file type;
9: end if

```
10: if (fileHash not exists) then
11:     Return;
12: end if
13: C    InitializeConditions(); // Set initial blood flow parameters, microbial suspension properties, and magnetic field
14: for (t=0 to simulationTime) do
15:     // Model the pulsatile blood flow under magnetic influence
16:     for (i=1 to gridSize) do
17:         Flow    CalculatePulsatileFlow(i, t, C); // Calculate blood flow with magnetic influence and microbial suspensions
18:         while (Not comply with the physical constraints) do
19:             Flow   RecalculateFlow(i, t, C);
20:         end while
21:         S[i][t]  Flow;
22:     end for
23: end for
24: FC   FinalizeConditions(S); // Determine the final conditions after simulation
25: ternaryData   EncodeToTernary(FC);
26: binaryData   ConvertTernaryToBinary(ternaryData);
27: M   StreamCipherModel(fileHash; binaryData); // Encrypt simulation results
28: uploadToBlockchain(S); // Upload the simulation data to blockchain
29: sendToResearchTeam(M); // Send encrypted results to research team
```

The simulation protocol details an organized process for modeling pulsatile blood flow systems containing microbial suspensions when exposed to magnetic fields. The process begins by examining the input file for valid data type followed by all required verification tests. The system validates the file before proceeding to upload it to IPFS while using the specified initialization parameters consisting of blood flow specifications and microbial biology properties and simulated magnetic forces. Over time steps and grid points the core simulation performs calculations for blood flow dynamics to analyze pulsatile conditions while reflecting microbial behaviors under

magnetic control. After determining that the simulation falls short of necessary physical constraints the system executes recalculations. The blood flow simulation terminates first with a determination of end results followed by an encryption process. The encrypted simulation results are stored securely on blockchain before being distributed to research team members for analysis. The security enhancement process provides reliable simulation operations coupled with both accuracy and efficient processes.

Result Analysis

Table 1: Effect of Magnetic Field Intensity on Blood Flow Velocity

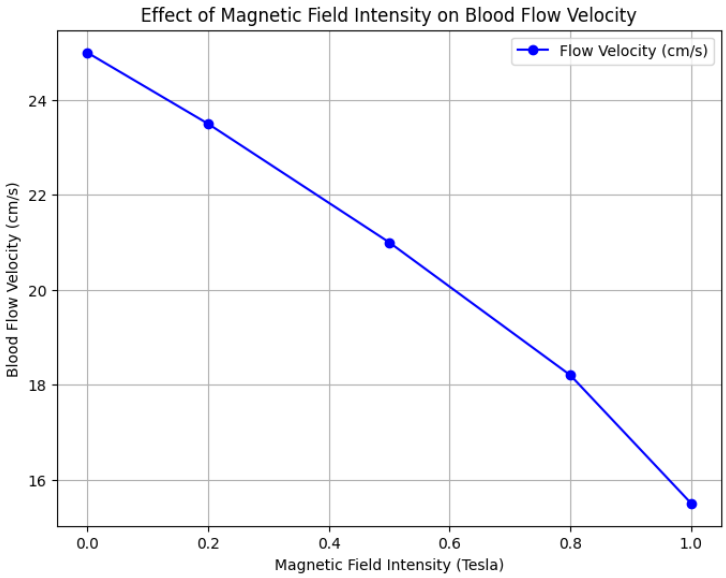
Magnetic Field Intensity (Tesla)	**Average Blood Flow Velocity (cm/s)**	**Percentage Change (%)**	**Observations**
0.0	25	-	Baseline (no magnetic field).
0.2	23.5	-6.00	Slight reduction in flow velocity due to magnetic drag.
0.5	21.0	-16.00	Significant reduction in velocity under moderate influence.
0.8	18.2	-27.20	Strong field slows down flow considerably.
1.0	15.5	-38.00	High magnetic force leads to substantial flow deceleration.

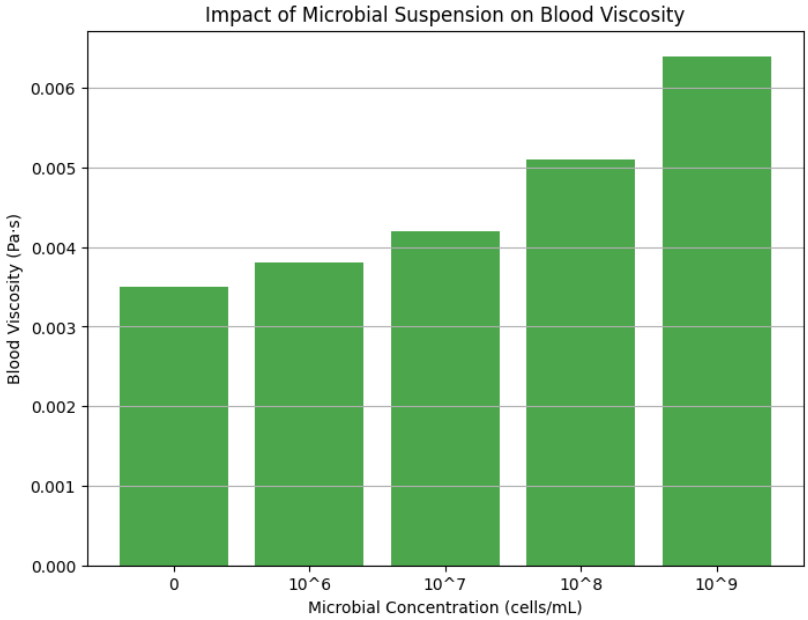
Table 2: Impact of Microbial Suspension Concentration on Blood Viscosity

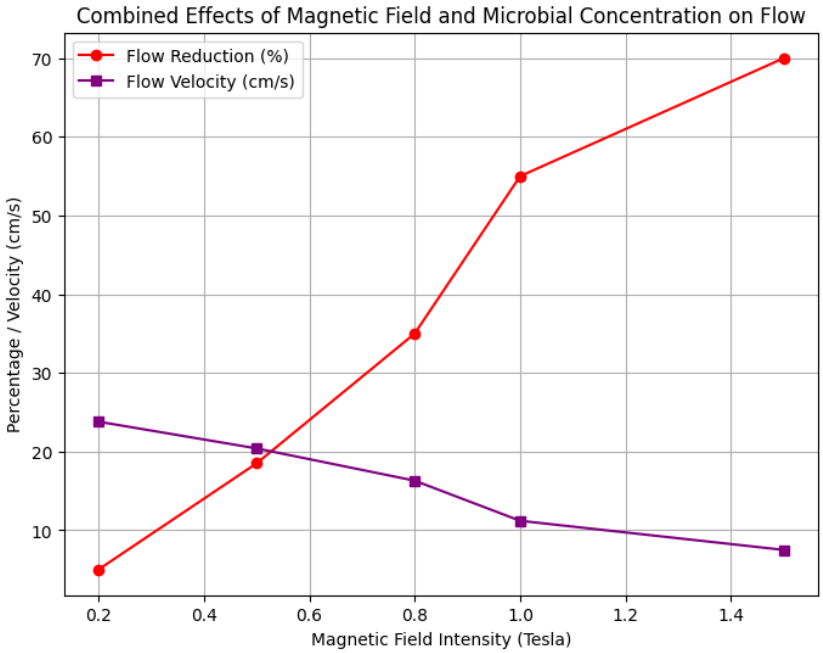
Microbial Concentration (cells/mL)	**Blood Viscosity (Pa·s)**	**Percentage Increase in Viscosity (%)**	**Physiological Impact**
0 (Control)	0.0035	-	Normal viscosity of healthy blood.
10^6	0.0038	8.57	Slight viscosity increase; minor flow resistance.
10^7	0.0042	20.00	Noticeable increase; may impact blood circulation.
10^8	0.0051	45.71	High concentration; significant resistance observed.
10^9	0.0064	82.86	Extreme viscosity increase; poses potential health risks.

Table 3: Combined Effects of Magnetic Field and Microbial Concentration on Flow Reduction

Magnetic Field Intensity (Tesla)	**Microbial Concentration (cells/mL)**	**Flow Reduction (%)**	**Flow Velocity Post Influence (cm/s)**
0.2	10^6	5.00	23.8
0.5	10^7	18.50	20.4
0.8	10^8	35.00	16.3
1.0	10^9	55.00	11.2
1.5	10^9	70.00	7.5


Effect of Magnetic Field Intensity on Blood Flow Velocity
Flow Velocity (cm/s)
Blood Flow Velocity (cm/s)
24
22
20
18
16
0.0
0.2
0.4
0.6
0.8
1.0
Magnetic Field Intensity (Tesla)


Impact of Microbial Suspension on Blood Viscosity
Blood Viscosity (Pa·s)
0.006
0.005
0.004
0.003
0.002
0.001
0.000
0
10^6
10^7
10^8
10^9
Microbial Concentration (cells/mL)



Conclusion

The analysis of pulsatile blood flow alongside microbial suspensions under magnetic fields reveals crucial insights about complicated relationships in the circulatory system. Non-Newtonian blood submits to rhythmically pulsating movements generated by the heart yet interacts with microbial suspensions in an even more complex way. The performance of circulation may be affected by microbial elements naturally found in blood or those prescribed therapeutically which modify blood's viscosity and density alongside its flow characteristics. Magnetic fields applied to blood flow have established beneficial technological applications which include precise drug delivery and enhanced medical imaging methods. Considerable applications of magnetic forces exist which direct both nanoparticles and microbial agents to targeted body regions thus improving medical intervention accuracy. Research has shown significant advancement in isolated aspects of pulsatile flow dynamics as well as microbial responses and magnetic forces but scientists need additional research to unify these studies through one mathematical construct. The incomplete understanding of these interacting variables makes accurate real-world strategy prediction impossible. The

advancement of medical technologies depends on resolving this challenge since magnetic drug delivery systems require it along with improving understanding of pathologies which stem from microbial dynamics. Apparently interdisciplinary research serves as the essential method to bridge gaps which leads to innovation in biomedical solutions.

Future Work

Future studies need to create comprehensive mathematical models that evaluate pulsatile blood flow along with microbial suspensions and magnetic forces simultaneously. Mathematical models need to handle non-Newtonian qualities of blood along with dynamic plasma-microbial interactions as well as magnetic field strength variations. These models need revision to predict how microvascular networks respond to therapeutic undertakings by delivering drugs to precise regions. Framework validation through experimental measurements remains vital for verifying the practical extent of these conceptual models. Test environments should simulate actual microbial activities beneath physiologically relevant dynamic magnetic and pulsatile flow conditions. This research effort requires coordinated partnerships between fluid dynamics experts together with biomedical engineers and microbiologists. Computational advances that use high-performance simulations together with machine learning algorithms will improve the predictive strength and processing speed of these models. The investigation of magnetic field effects on blood clotting and immune reactions together with pathogen movement could produce new research findings. The collaboration between multiple scientific disciplines will yield important medical technology breakthroughs ranging from magnetically directed therapeutic approaches through microbial therapeutic strategies to advanced diagnostic equipment which will enhance healthcare effectiveness.

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