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CONSTRUCTION OF A VISCOUS BLOOD FLUID DYNAMICS MODEL AND ITS APPLICATION IN INNOVATION DIFFUSION

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Abstract. A blood fluid dynamics model based on viscosity correction has been proposed. In the process of constructing this model, the Lagrangian trace equation of blood fluid dynamics was first explained, and then combined with the laws of mass conservation, energy conservation, and transformation, the continuity equation, motion equation, and energy equation of blood flow were gradually derived. Finally, the model of blood fluid dynamics was obtained with the correction of blood viscosity. The blood fluid dynamics model was applied to the innovation diffusion experiment in enterprises, taking into account the path bifurcation problem in innovation diffusion. The topological structure of complex enterprise innovation diffusion was verified under the Fluent platform, and the linear effect of viscosity coefficient on innovation diffusion was found to be negative.

1. Introduction

Biomechanics is a branch of biophysics that applies principles and methods of mechanics to quantitatively study mechanical problems in living organisms [2, 7, 8]. Its research scope ranges from the whole organism to systems and organs, including blood, body fluids, organs, bones, etc. It can also be extended to bird flight, fish swimming, flagella and cilia movement, and the transportation of plant body fluids [6, 13, 18].

The foundation of biomechanics is the laws of energy conservation, momentum conservation, and mass conservation, combined with constitutive equations that describe physical properties [4, 11]. The focus of biomechanical research is on mechanical issues related to physiology and medicine. According to the different research objects, it can be divided into biofluid mechanics, biosolid mechanics, and sports biomechanics [5, 14].

Hemohydrodynamics refers to the mechanics of blood flow in the cardiovascular system, mainly studying blood flow, blood flow resistance, blood pressure, and their interrelationships. Blood is a fluid, so the basic principles of hemodynamics are the same as those of general fluid mechanics [16]. However, due to the fact that the vascular system is a complex elastic pipeline system, blood is a liquid containing various components such as blood cells and colloidal substances rather than an ideal liquid. Therefore, hemodynamics have both the commonalities of general

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fluid mechanics and its own characteristics [1]. Montenegro conducted a systematic analysis of blood circulation based on the principle of continuity in fluid mechanics and validated it through frog lung microvasculature [12]. Rowley established the Poisson's theorem for laminar flow in a straight circular tube by measuring the arterial blood pressure in dogs, enriching the hemodynamics of blood [15]. To explore the relationship between blood pressure and blood loss, Chong introduced the concept of peripheral resistance in blood flow and pointed out that this resistance mainly comes from microvessels in tissues [3]. Changes in blood viscosity can also affect blood flow resistance. Under constant other factors, the higher the viscosity, the greater the vascular resistance. The viscosity of normal blood is 4-5 times that of water [9]. The analysis of blood fluid dynamics is a complex process, but the rapid development of computational science has made it easy to simulate blood fluid dynamics through computational models, thereby expanding its application scope [10]. Blood fluid dynamics can be applied in scenarios similar to blood flow [17].

It can be seen that blood fluid dynamics has extensive research value, and it is of great significance to comprehensively consider key parameters such as blood viscosity and construct a blood fluid dynamics model. On the basis of biomechanics, this article establishes a viscosity based blood fluid dynamics model and extends it to the field of enterprise innovation diffusion for application.

2. Methodology

2.1. **Blood fluid dynamics model.** Fluid motion should follow the universal laws of mechanical motion, and the fundamental laws in fluid mechanics are essentially the specific applications and manifestations of mechanical universal laws in fluid mechanics. Biofluid mechanics is a science based on fluid mechanics problems and basic theories in biological life phenomena. It is an interdisciplinary field that combines fluid mechanics and biomedicine. The study of biofluid dynamics reveals the inherent relationship between human diseases and biomechanical characteristics.

There are two methods for describing the movement of blood fluids, namely the Lagrangian method and the Euler method. The Lagrangian method is a method of studying the movement of individual blood particles in a flow field, studying the changes in physical quantities of individual blood particles and the changes in these quantities when one blood particle transitions to other fluid particles. Essentially, it expresses the movement of blood using time and blood particles.

After providing the identification of each blood particle, its physical quantity can be expressed using identification and time. When a certain set of definite values is assigned, it means tracking this specific blood particle to examine its motion. The trace equation of Lagrange is shown in Equation (2.1):

$$\begin{cases} x = x(a,b,c,t) \\ y = y(a,b,c,t) \\ z = z(a,b,c,t) \end{cases} . \tag{2.1}$$

Here, x is the x-axis coordinate of the blood particle at time t, y is the y-axis coordinate of the blood particle at time t, z is the z-axis coordinate of the blood particle at time t, and a, b, c, and t represents the Lagrange coefficients.

Due to the smooth connection of all physical quantities, each physical quantity has a partial derivative. The partial derivative of the coordinates of each particle in blood with respect to time is the velocity value of the particle, that is shown in Equation (2.2):

$$\begin{cases} u_x = \frac{\partial x}{\partial t} = \frac{\partial x(a,b,c,t)}{\partial t} \\ u_y = \frac{\partial y}{\partial t} = \frac{\partial y(a,b,c,t)}{\partial t} \\ u_z = \frac{\partial z}{\partial t} = \frac{\partial z(a,b,c,t)}{\partial t} \end{cases}. \tag{2.2}$$

Here, u_x is the velocity of blood particles in the x direction, u_y is the velocity of blood particles in the y direction, and u_z is the velocity of blood particles in the z direction.

The second partial derivative of the coordinates of each particle in the blood fluid with respect to time is the acceleration value of the particle, which is shown in Equation (2.3):

$$\begin{cases} a_x = \frac{\partial^2 x}{\partial t^2} = \frac{\partial^2 x(a,b,c,t)}{\partial t^2} \\ a_y = \frac{\partial^2 y}{\partial t^2} = \frac{\partial^2 y(a,b,c,t)}{\partial t^2} \\ a_z = \frac{\partial^2 z}{\partial t^2} = \frac{\partial^2 z(a,b,c,t)}{\partial t^2} \end{cases}. \tag{2.3}$$

Here, a_x is the acceleration of blood particles in the x direction, a_y is the acceleration of blood particles in the y direction, and a_z is the acceleration of blood particles in the z direction.

Blood flow, like general fluids, follows the three laws of conservation in physics: the law of mass conservation, the law of momentum conservation, and the law of energy conservation.

(1) Continuity equation

The theoretical basis of the continuity equation is the law of conservation of mass, which is defined as the constant mass of an object during its motion. It reflects the relationship between fluid motion and mass distribution, as shown in Equation (2.4):

$$\int_{\Delta} \frac{\partial \rho}{\partial t} d\Delta + \int_{\sigma} \rho v d\sigma = 0. \tag{2.4}$$

Here, Δ represents any volume of blood fluid in the blood flow field, σ represents the peripheral interface of blood fluid, ρ represents the density of blood fluid, and v represents the velocity of blood fluid. As can be seen, the first part of the Equation represents the rate of increase in blood fluid mass within the volume, while the second part represents the mass of blood fluid within the volume.

(2) Equation of motion

The equation of motion, also known as the energy equation, is based on the law of conservation of momentum. The law of conservation of momentum states that the vector sum of all external forces acting on an object is equal to the rate of change of the object's momentum over time. It reflects the mathematical expression between the motion of blood fluid and its force, as shown in Equation (2.5):

$$\int_{\Delta} \rho \frac{dv}{dt} d\Delta = \int_{\Delta} \rho F d\Delta + \int_{\sigma} P d\sigma. \tag{2.5}$$

Here, F represents the force acting on a unit mass of blood fluid, and P represents the stress tensor, which is reflected in the force density on the cross-section. The left side of the Equation represents the rate of change of total momentum within the volume, the first part on the right side represents the comprehensive intemal force of the volume, and the second part on the right side represents the total cross-sectional force within the volume.

If the rate of change of total momentum within a volume is regarded as the inertia force per unit volume, the law of momentum change can be explained as the total inertia force being balanced with the total external force, resulting in zero resultant torque.

(3) Energy equation

The theoretical basis of the energy equation is the law of conservation and conversion of energy, which indicates the transfer of mass from the outside world.

The difference between the heat of the system and the work done by the system to the outside world is equal to the energy increase of the system, in the Equation (2.6):

$$\int_{\Delta} \rho \frac{d}{dt}\left(U+\frac{v^2}{2}\right) d\Delta = \int_{\Delta} (\rho F v + \rho q) d\Delta + \int_{\sigma} \left(Pv + k\frac{\partial T}{\partial n}\right) d\sigma. \tag{2.6}$$

Here, U represents the internal energy of a unit mass of blood fluid, q represents the heat generated by a heat source to a unit mass of blood fluid per unit time, v represents the velocity of blood fluid, F represents the force acting on a unit mass of blood fluid, T represents thermodynamic temperature, and k represents thermal conductivity. The left side of the Equation represents the rate of time change of the total energy of the blood fluid in the volume, the first part on the right side represents the sum of the work done by the intemal force per unit time and the heat generated by the heat source, and the second part on the right side represents the sum of the work done by the heat transfer interface force and the heat flowing into the volume.

2.2. **Correction of blood viscosity on the model.** A biomechanical model of blood flow was established using the continuity equation, motion equation, and energy equation mentioned earlier. In fact, the process of blood fluid movement can also be influenced by other factors. Among them, blood viscosity is a very important factor that affects blood flow.

Due to the presence of viscosity, the speed of blood flow is affected, which in turn affects the supply of blood in the vascular topology network. Here, the influence of blood viscosity on blood flow velocity is shown in Equation (2.7).

$$\begin{cases} \rho v \nabla v + \nabla p - \mu^{\Delta v} = 0 \\ \nabla v = 0 \end{cases} \tag{2.7}$$

Here, ρ represents the density of blood fluid, v represents the velocity of blood fluid, ∇ represents gradient operator, p represents pressure inside blood vessels, μ represents blood viscosity coefficient, and Δv represents changes in blood flow velocity.

It can be seen that the presence of blood viscosity will inhibit blood flow velocity, leading to a gradual approach of zero blood flow velocity. In the research process of

this article, Equation (2.7) was used to further modify the biomechanics of blood fluid to better match the actual situation. At this point, a complete viscosity based blood fluid dynamics model has been established.

3. Experiments

The viscosity based blood fluid dynamics model described in Equation (2.1) - (2.7) can be applied not only to the analysis of blood circulation, but also to other fields. In this article, the wider practicality of this biomechanical model is verified through experiments in the diffusion process of enterprise technological innovation.

3.1. **The Corresponding Relationship between Enterprise Innovation Diffusion and Blood Flow Model.** In order to facilitate the application of the biological model established in this article in the study of enterprise innovation diffusion, the key elements between the two are first correspondingly configured, as shown in Table 1.

Table 1. Corresponding Key Elements of Innovation Diffusion and Blood Flow in Enterprises

	Innovation Diffusion Factors	Blood Flow Factors
1	Innovation diffusion	Blood flow
2	Enterprises exporting innovative achievements	Heart
3	Enterprises introducing innovative achievements	Other organs and body parts
4	Innovation diffusion system	Human circulatory system
5	The resistance of innovation diffusion environment	Blood viscosity
6	Innovation diffusion path	The route of blood flow

3.2. **The impact of bifurcation.** In the process of enterprise innovation diffusion, an innovation achievement may be needed by multiple enterprises simultaneously. At this point, in the innovation diffusion network, innovation diffusion faces the problem of diffusion from one path to multiple paths. Corresponding to the circulatory system, this morphology manifests as bifurcation of blood vessels. For this common situation, which may occur at any time during the simulation experiment, it is characterized by the shape shown in Figure 1. Branching of blood vessels may also result in more than two forks, such as three forks, four forks, or more. For a trifurcation, we can understand it as a branch on a bifurcated branch, the result of further bifurcations. Similarly, situations with multiple forks can be explained.

In Figure 1, several random cases of bifurcation are shown. In the simulation environment, as long as the position and angle of the bifurcation are set, the branching path of innovation diffusion can be accurately described. Similarly, an accurate description of vascular bifurcation in the circulatory system can also be provided.

Based on the above considerations, provide a topology diagram of enterprise innovation diffusion, as shown in Figure 2.

In Figure 2, node A represents the enterprise with technological innovation achievements, and it is also the original enterprise of technological innovation diffusion. There are two target enterprises that accept technological innovation achievements, one is node B and the other is node C. Of course, the innovative achievements of

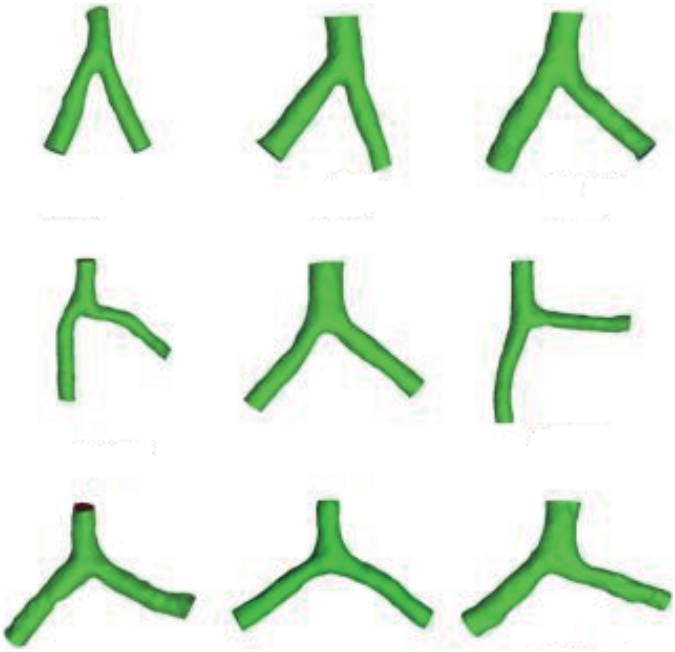

FIGURE 1. Innovation diffusion path and bifurcation situation faced in blood flow

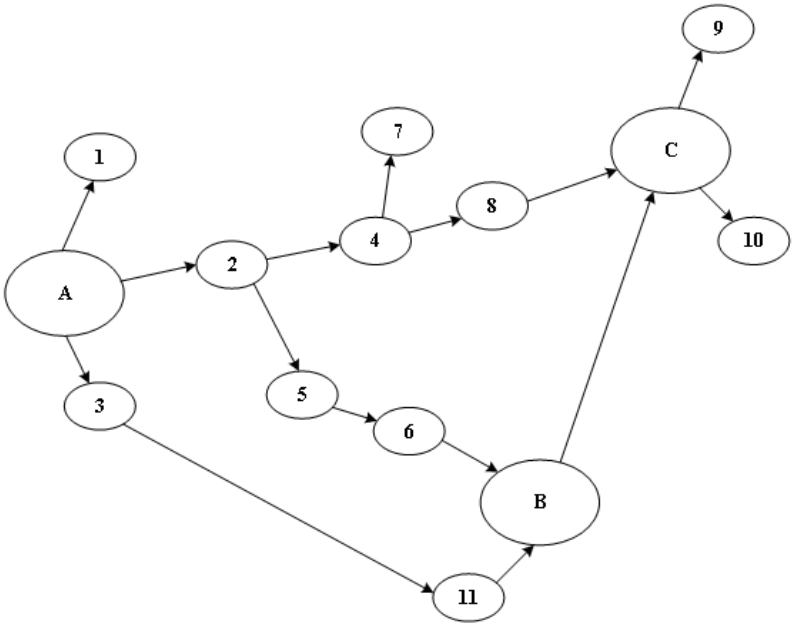

FIGURE 2. Topological structure diagram of enterprise innovation diffusion

node A can also spread to a larger scope, such as the diffusion from node A to node 1. There are two paths for the diffusion of technological achievements from node A to node B. One is node A -¿node 3-¿node 11-¿node B, and the other is node A -¿node 2-¿node 5-¿node 6-¿node B. There are two paths for the diffusion of technological achievements from node A to node C. One is node A -¿node 2-¿node 4-¿node 8-¿node C, and the other is node A -¿node 2-¿node 5-¿node 6-¿node B -¿node C. Of course, after the innovative achievements reach node B or node C, they can further spread, such as the diffusion from node C to nodes 9 and 11. This is similar to the capillary part of the circulatory system.

3.3. **Simulation of Complex Diffusion Topological Relationships.** After establishing the theoretical model and experimental conditions mentioned above, Fluent software was chosen as the simulation platform to verify the formation of the complex topology structure of enterprise innovation diffusion. Fluent is a popular fluid dynamics simulation software internationally, with a market share of 60% in the United States. It can be used in industries related to fluids, heat transfer, and chemical reactions. It has rich physical models, advanced numerical methods, and powerful pre-processing and post-processing functions, and is also widely used in the analysis of biological fluid dynamics.

Taking into account a large and complex enterprise community, the innovation diffusion topology structure obtained through simulation using the viscosity based blood fluid dynamics model established in this article is shown in Figure 3.

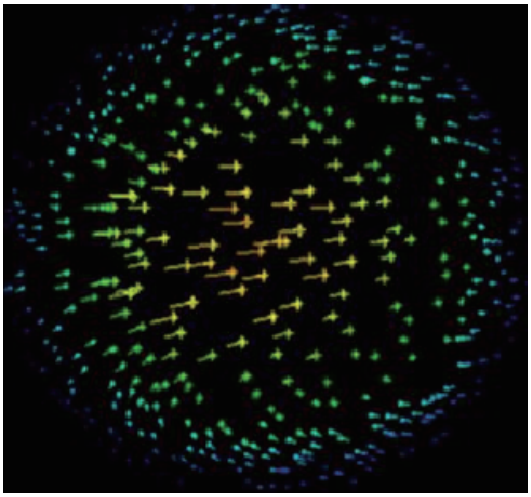

FIGURE 3. Topological structure of the speed of each node in enterprise innovation diffusion

From Figure 3, it can be seen that the central area of the enterprise community contains multiple enterprises, while the peripheral area has a larger number of small enterprises that are also affected by innovation diffusion and participate in the process of innovation diffusion. The overall direction of innovation diffusion is from left to right. The length of the arrow in the central area represents the intensity of diffusion, while the front direction represents the direction of diffusion. It can be

seen that the blood fluid dynamics model based on viscosity can be used for the study of innovation diffusion problems in enterprises, and clear diffusion results and topological structures can be obtained.

3.4. **The influence of viscosity parameters on innovation diffusion.** Further investigate the influence of viscosity parameters on innovation diffusion in the process of innovation diffusion. In the analysis of blood flow problems, the viscosity parameter is the blood viscosity. For the issue of innovation diffusion, stickiness refers to the resistance of the innovation diffusion environment to diffusion behavior, which is exactly the opposite of innovation diffusion behavior, attempting to organize the flow of technological achievements between enterprises.

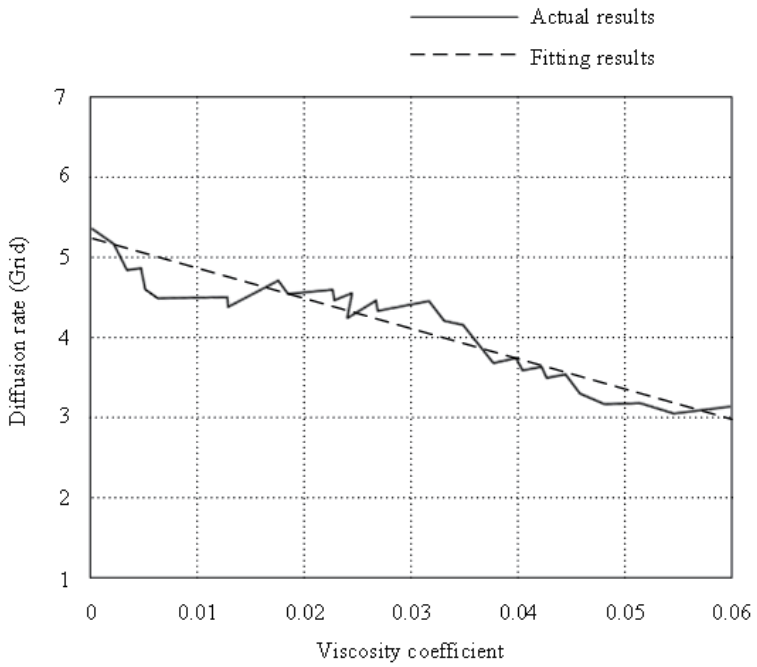

FIGURE 4. The influence of viscosity parameters on innovation diffusion speed

In Figure 4, the horizontal axis represents the size of the viscosity parameter, increasing from 0 to 0.06. The vertical axis represents the speed of innovation diffusion, represented by Grid in a simulation environment. From the graph, it can be seen that the larger the viscosity parameter, the slower the speed of innovation diffusion. According to the fitting results obtained from actual data, it can be seen that the influence of viscosity parameters on innovation diffusion is approximately linear.

4. Conclusion

The research work in fluid mechanics has laid the foundation for the biomechanical analysis of blood flow, and blood fluid dynamics models can also break through

the limitations of this field and expand their applications to other fields. In this article, starting from the Lagrangian trace equation of blood fluid dynamics, combined with the laws of mass conservation, energy conservation, and transformation, the continuity equation, motion equation, and energy equation of blood flow are gradually derived, thereby constructing a fluid dynamics model of blood fluid. Furthermore, the influence of blood viscosity on blood flow was considered, and the blood fluid dynamics model was modified accordingly. During the experiment, the blood fluid dynamics model was corresponding to the innovation diffusion problem in enterprises. The practicality of the model was verified on the Fluent platform, and the topological structure in complex enterprise innovation diffusion was obtained. The influence of viscosity parameters on innovation diffusion was quantified.

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