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PARTIAL - BOUNCE BACK LATTICE BOLTZMANN METHOD FOR IMMISCIBLE BINARY FLUIDS THROUGH POROUS MEDIA

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ABSTRACT

Lattice Boltzmann equation is frequently used as a simulation tool which has advance effect on the complex fluids such as multiphase and multicomponent flows through porous media. Three different models are suggested for two immiscible binary fluids with variable viscosities and density ratio. Average velocity and density profiles are plotted against solid fraction. Separation phenomena for three models has been analyzed.

1. INTRODUCTION

The lattice Boltzmann method is often described as a simulation tool that is particularly effective for complex fluids such as multiphase and multicomponent flows through porous media. To characterise the flow at pore scale it is convenient to use simplified representations of porous media, such as physical micromodels which can be constructed in the form of pseudo two dimensional capillary networks. The experimental analysis of the problem is very difficult; simulation can be a very useful complementary method. The lattice Boltzmann method is of utmost importance due to its ability to model a variety of fluids [1,2,3] . It can handle complex and changing Bc's and geometries [4,5].

The first lattice gas model for immiscible binary fluids was proposed by [6] and the equivalent lattice BGK (LBGK) model was proposed by [7]. The model for binary fluids with different density ratios and viscosities on a triangular lattice in two dimensions was modified by [8].

A meso scale lattice Boltzmann model is introduced by [9] as an alternative approach that deals the permeability of the medium as a model parameter. For simulating porous materials on large scales, LB models have been proposed in [10, 11].

LB models are quiet popular as these methods provide a convenient means to simulate the true pore geometry of the porous medium for single fluids and multiphase flow. A new particle bounceback lattice – Boltzmann method for fluid flow through heterogeneous media has been investigated by [12].

An analytic expression for calculating the permeability has been derived for the described models. In the present investigation the partial bounceback lattice Boltzmann model is constructed for immiscible binary fluids through porous media. Equillibrium distribution functions are described with the recoloring algorithm. The analysis has been carried out for three models with two immiscible fluids.

2. MODELING

2.1. Model 1. Outgoing bounce back:

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Let f_a^r, f_a^b and f_a denote the particle distribution functions of a red fluid, a blue fluid and the mixture respectively. The macroscopic variables are

$$\rho^r = \sum f_a^{\ r} \quad , \quad \rho^b = \sum f_a^{\ b}$$
$$\rho = \rho^r + \rho^b , \qquad u = \frac{1}{2\rho} \sum \xi_a (f_a^{\ r} + f_a^{\ b}) \tag{1}$$

The order parameter in the system of a binary mixture is

$$\phi = \frac{\rho^r - \rho^b}{\rho_r + \rho_b} \tag{2}$$

The fluid packets following the bounceback step are a weighted sum of the incoming fluid packet prior to the collision step, the outgoing fluid packets following the collision step. The LBE for both red and blue fluid packets under the outgoing bounceback.

$$f_a^{\ B}(t + \Delta t, x + \xi_a t) = \ f_a \ (t, x) + \Delta t \Omega_a^{\ R}(t, x), \ \ a = 1,2.......N - 1$$
$$= \ \ f_a^{\ R}(t, x) - n_s \ f_a^{\ R}(t, x) + n_s f_a^{\ B}(t - \Delta t, x) + \Delta t \Omega_a^{\ R}(t, x) \tag{3}$$

$\Omega_a^{\ R}(t, x)$ is the collision operator. The collision operator is made of three parts:

$$\Omega_a^{\ R} = \Omega 3_a^{\ R} \left\{ \Omega 1_a^{\ R} + \Omega 2_a^{\ R} \right\} \tag{4}$$

Where $\Omega 1_a^{\ R}$ is the usual single relaxation parameter, $\Omega 2_a^{\ R}$ is the operator responsible for the generation of surface tension and $\Omega 3_a^{\ R}$ represents the recoloring which mimics the separation mechanism. The proportion of fluid reflected at each mode is instead controlled by a model parameter denoted the solid fraction n_s.

2.2. Model 2.

The second approach is the post collision bounceback:
In this case the LBE for red and blue packets are:

$$f_a^{\ B}(t + \Delta t, x + \xi_a t) = f_a^{\ R}(t, x)(1 - n_s) + n_s f_a^{\ B}(x + c_a \Delta t, t) + \Delta t \Omega_a^{\ R}(t, x) \tag{5}$$

To evaluate the density of blue fluid packet, after collision , the collision step is first calculated at each node in the lattice.

2.3. Model 3.

The third approach is the pre collision bounceback:
In this approach the density of incoming fluid packets prior to the collision step is considered.

$$f_a^{\ B}(t + \Delta t, x + \xi_a t) = (1 - n_s) f_a^{\ R}(t, x) + \ f_a^{\ B}(t, x) \tag{6}$$

The results presented in this paper are obtained using D3Q19 lattice Boltzmann models (where the numbers following the D and the Q refer to the model dimensionality and number of lattice speed respectively).

3. SIMULATIONS

1) Density profile of red and blue packets with lattice spacing for different models.
2) Velocity of red and blue packets before collision
3) Velocity of red and blue packets after collision
4) Separation phenomenon of red and blue packets at different time steps

Simulations are used to illustrate the ability of three models with regard to density profiles, velocity configuration and separation phenomena. The study reveals the importance of LBE for the study of binary immiscible fluids. The results obtained for three models are absolutely different and justify previous investigations.

The graphical analysis has been done for density, velocity before collision, velocity after collision and seperation phenomena for red and blue packets for three models. The results clearly predict that the configration is different for different cases.

Density confegration with lattice spacing has been investigated, For model 1, the periodic behavior of red and blue fluid packets have been observed, for model 2 the spike increase at initial stage and then wave behavior is observed while for model 3, there is bounceback in red fluid packets and blue fluid packets and density profiles does not connect anywhere, complete isolation is there. Similiarly the average velocity analysis has been done for all three models.

The behaviour against solid fraction is different for models.For blue fluid packet it increases sharply, but for red fluid packets it increases very slowly. The seperation phenomena has been critically visualized for three models.

4. RESULTS AND DISCUSSIONS

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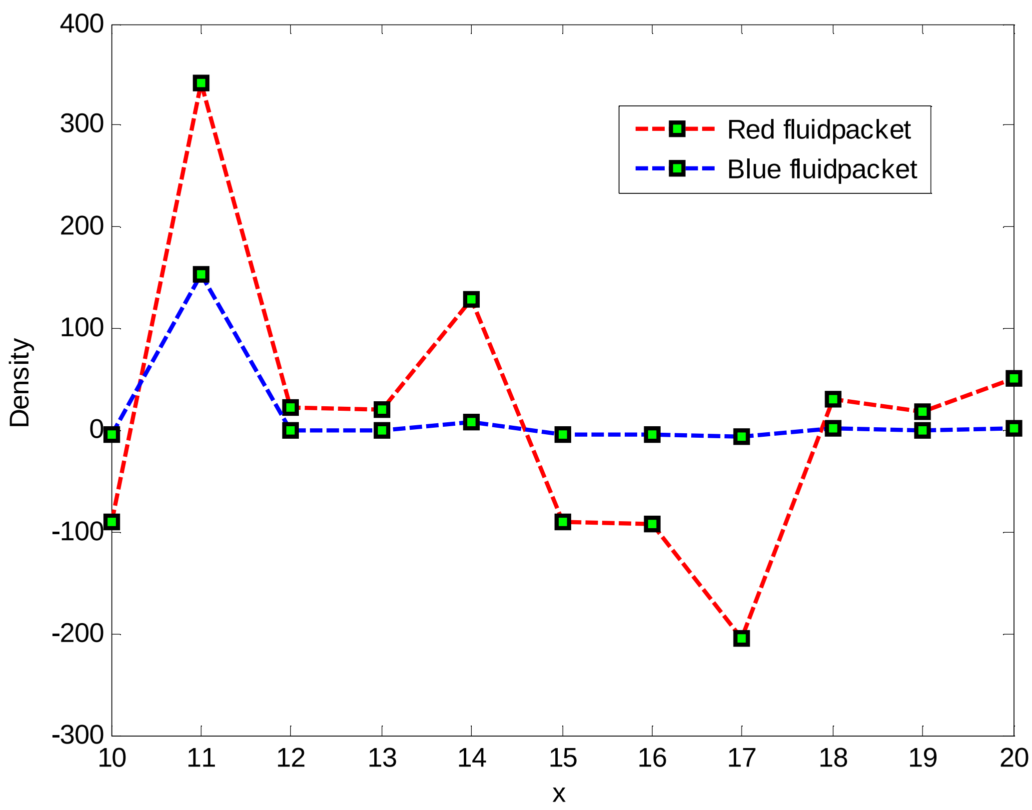

Figure 1 Density profile against lattice spacing for Model 1

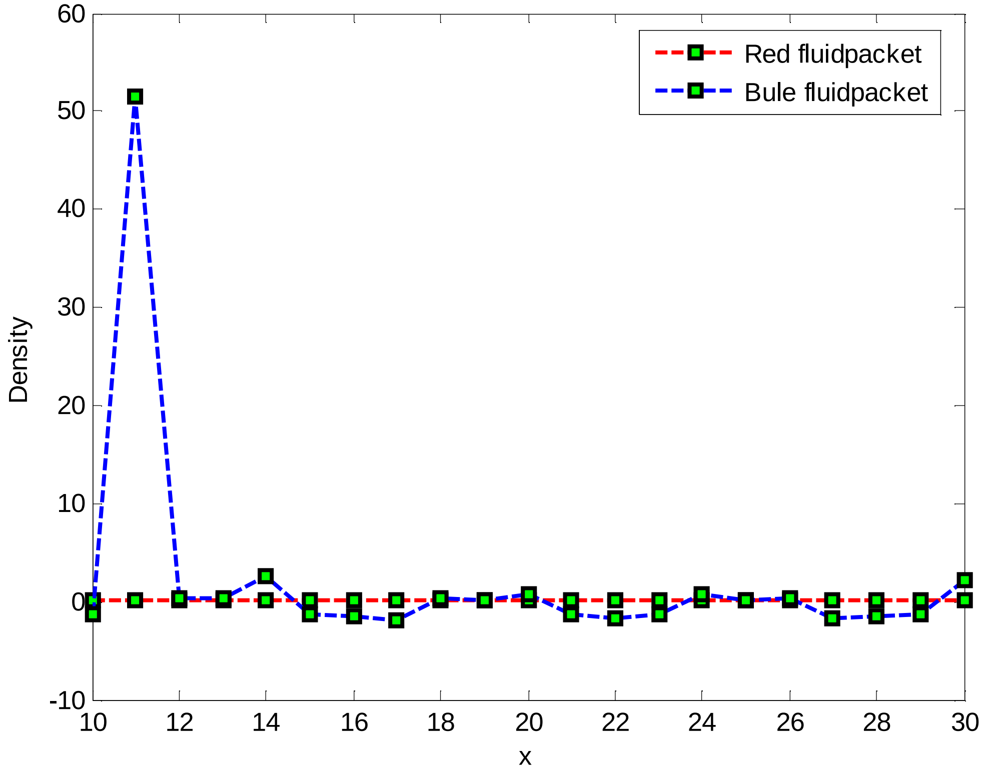

Figure 2 Density Profile against latticespacing for Model 2

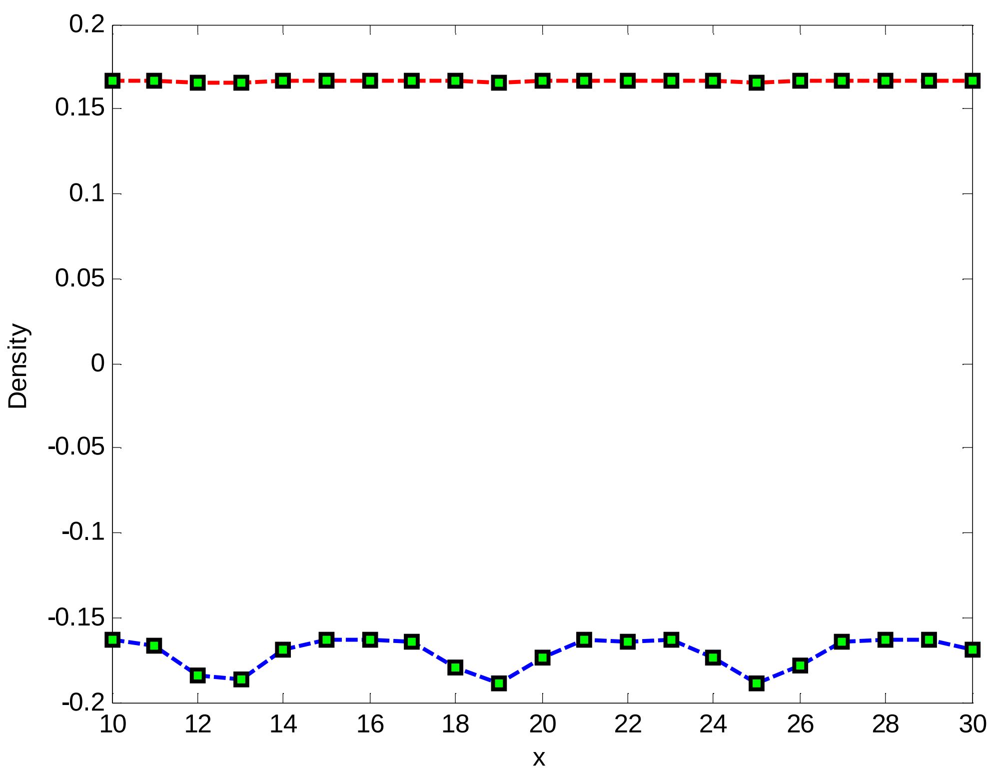

Figure 3 Density profile against lattice spacing for Model 3

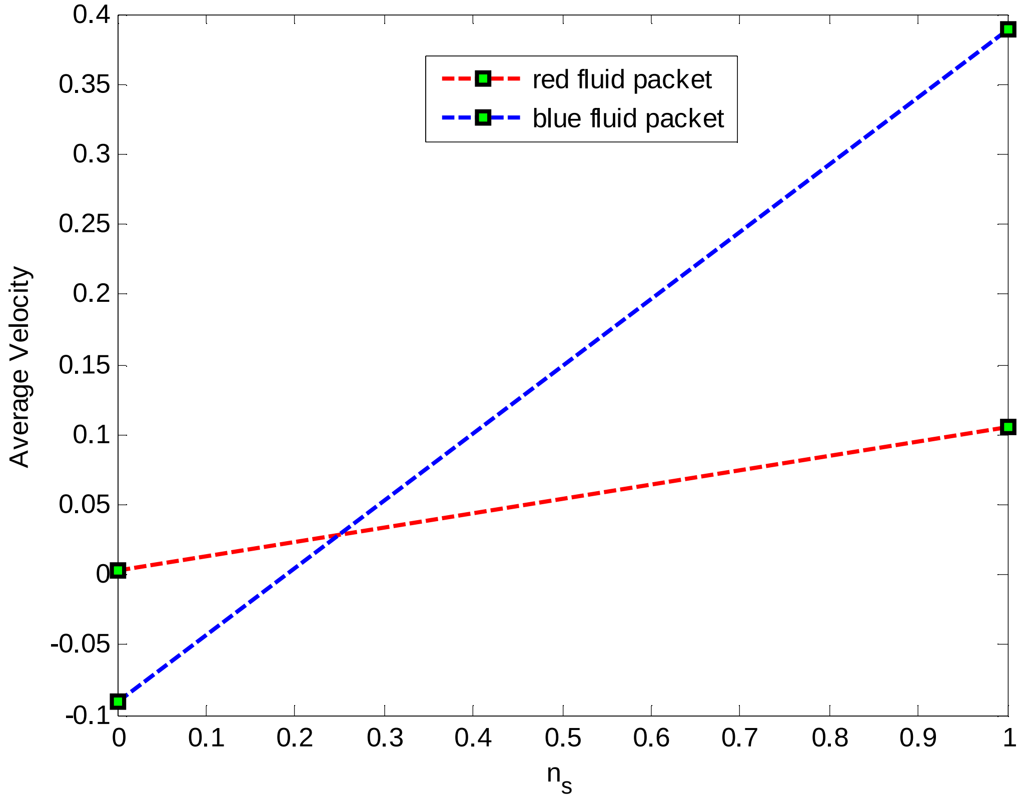

Figure 4 The average velocity against solid fraction for model 1

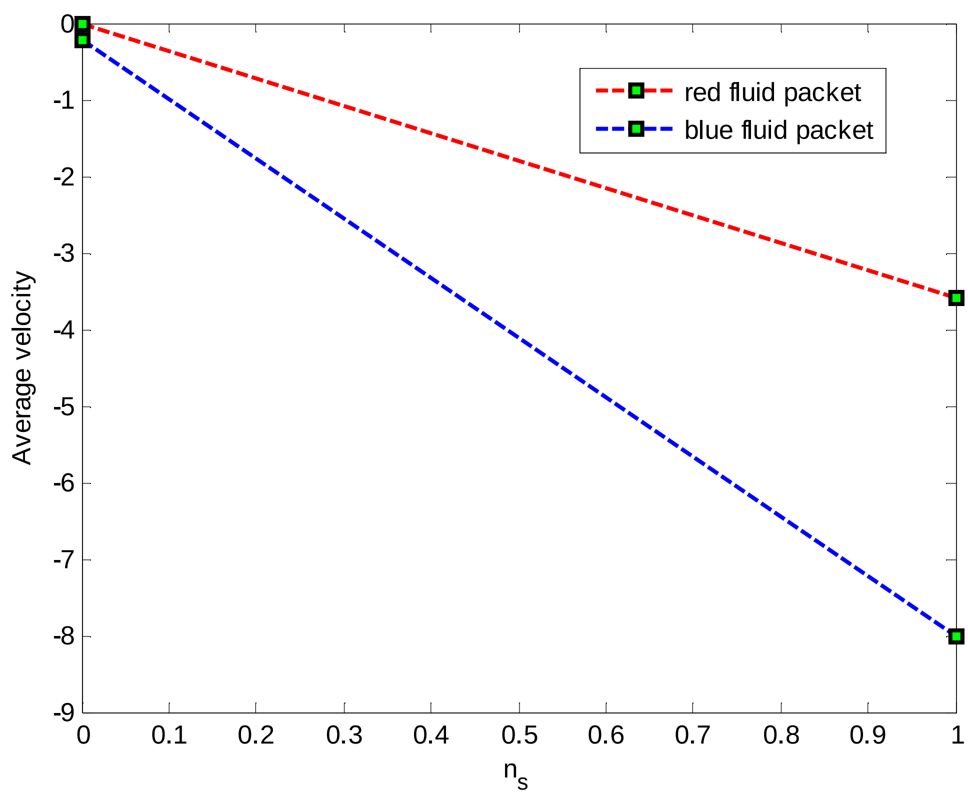

Figure 5 Average velocity against solid fraction for Model 2

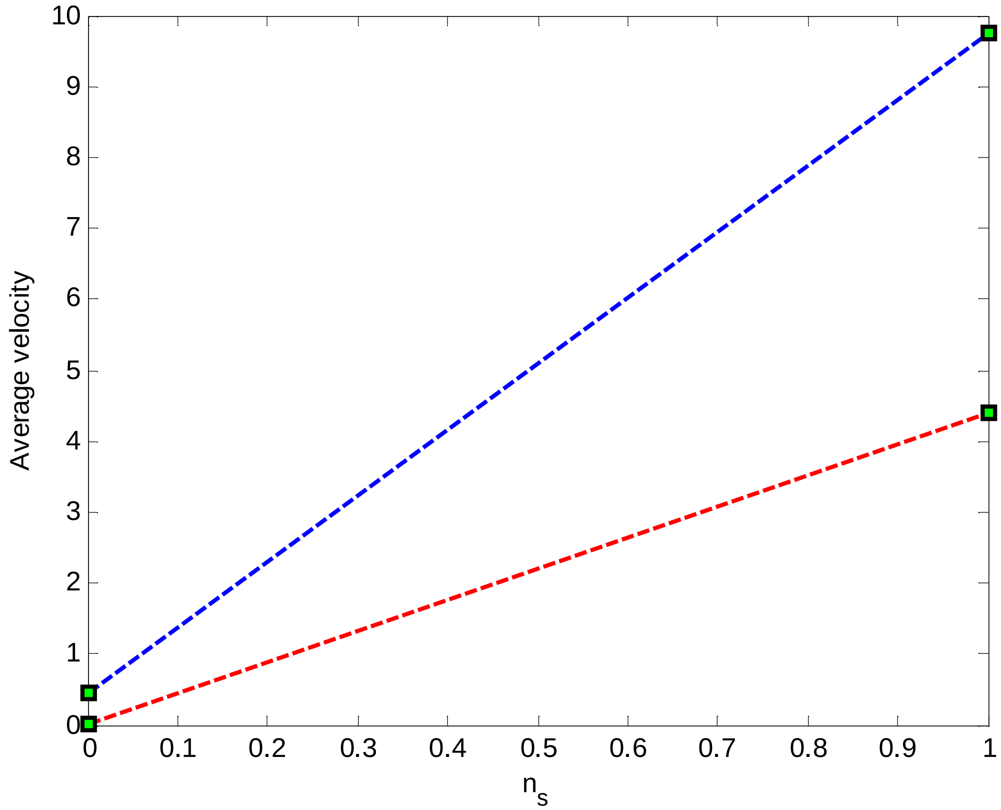

Figure 6 Average velocity against solid fraction for Model 3

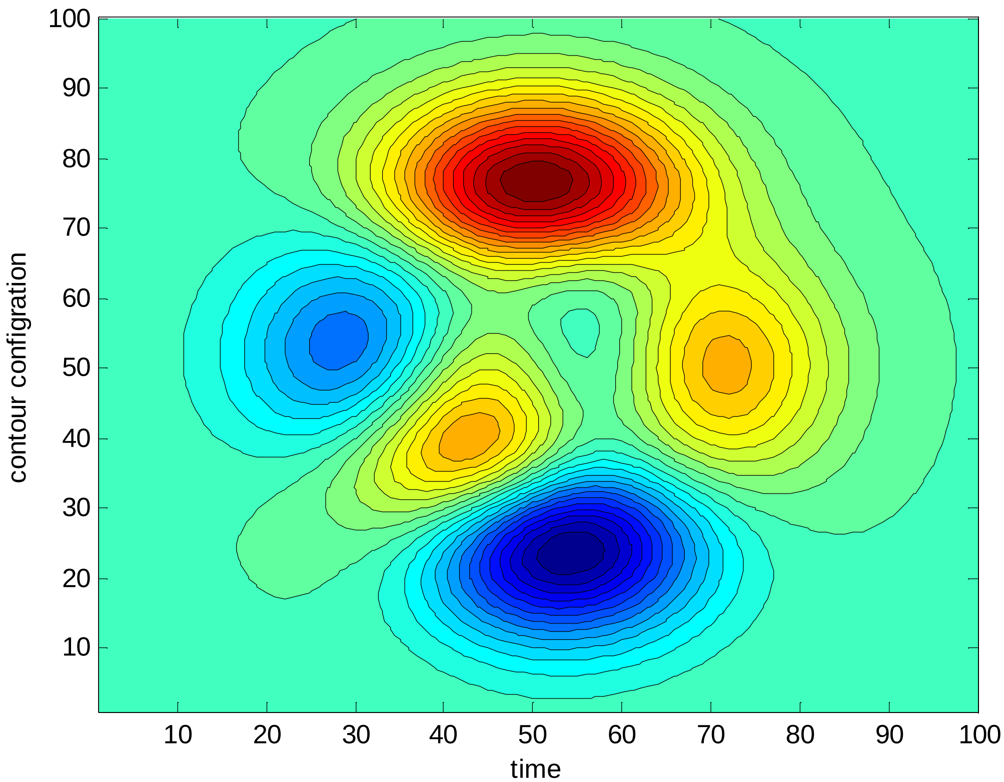

Figure 7 Seperation phenomena of red and blue packets at different time steps for model 1

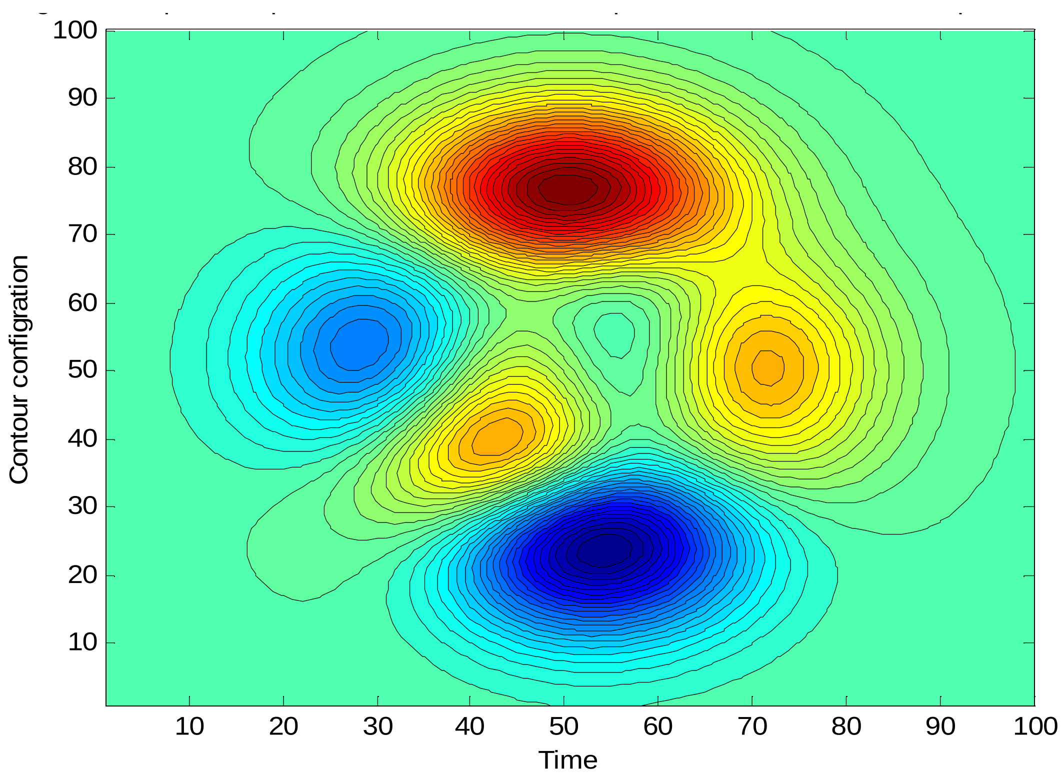

Figure 8 Separation phenomena of red and bule packets at different time steps for model2

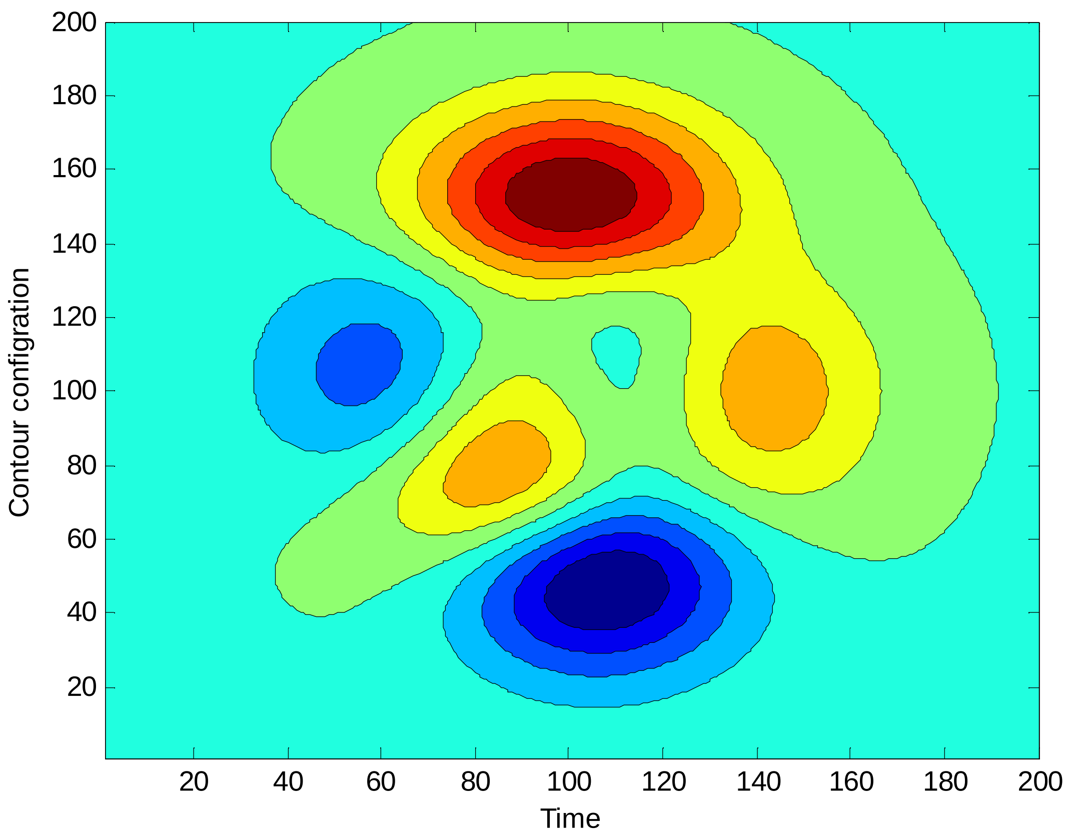

Figure 9 Separation phenomena of red and blue fluid packets at different time steps for model 3

5. ACKNOWLEDGEMENT

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