Magnetic Reconnection in Chromospheric Current Sheet in the Presence of Ambipolar Diffusion and Different Ionization Fraction

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Abstract

The solar chromosphere possesses complex magnetic structuring and plasma dynamics at diverse spatio-temporal scales. Using MPI-AMRVAC, we have modeled the chromospheric magnetic reconnection process by externally perturbing a localized horizontal current sheet (CS) in the presence of radiative cooling, thermal conduction, different ambipolar diffusion (AD) and ionization fraction. Due to the pressure gradient across the CS, the magnetic fields are trying to reconnect at the centre of the CS, generating bidirectional plasma outflows. Due to the presence of AD, the reconnection rate is decreasing, because both average pressure and temparature of the CS are increasing significantly such that it is resisting the magnetic field from annihilating at the X point. In this entire reconnection process, magnetic energy loss rate is less for higher AD for which, joule heating, kinetic energy and internal energy increase at a lower rate. The outflow plasma speed is about 20 km s^{-1} that is equivalent to the speed of observed typical cool chromospheric jets. The average temperature of the cool chromospheric plasma is elevated up to middle chromospheric temperature at around 35000 K. We further include different ionisation fraction in our simulation. In the case of partially ionized plasma, reconnection rate remains same and no significant variation in temperature and other physical quantites have been observed.

Numerical Methods

(i) To model chromospheric reconnection, we have used open source **MPI-AMRVAC** code to solve the Magneto-hydrodynamic (MHD) equations.

(ii) All the MHD equations like induction equation, continuity, momentum and energy equation are temporally and spatially discritized by finite difference method.

$$\frac{\partial \rho}{\partial t} = -\nabla\cdot(\rho \mathbf{v}),$$

$$\frac{\partial(\rho \mathbf{v})}{\partial t} = -\nabla\cdot\left[\rho\mathbf{v}\mathbf{v} + \left(p + \frac{1}{2\mu_0}|\mathbf{B}|^2\right)I - \frac{1}{\mu_0}\mathbf{B}\mathbf{B}\right] + \nabla\cdot\tau_S,$$

$$\frac{\partial e}{\partial t} = -\nabla\cdot\left[\left(e + p + \frac{1}{2\mu_0}|\mathbf{B}|^2\right)\mathbf{v}\right] + \nabla\cdot\left[\frac{1}{\mu_0}(\mathbf{v}\cdot\mathbf{B})\mathbf{B}\right] + \nabla\cdot\left[\mathbf{v}\cdot\tau_s + \frac{\eta}{\mu_0}\mathbf{B}\times(\nabla\times\mathbf{B})\right] - \nabla\cdot\left[\frac{1}{\mu_0}\mathbf{B}\times\mathbf{E}_{AD}\right] + Q_{rad} + H,$$

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla\times(\mathbf{v}\times\mathbf{B} - \eta\nabla\times\mathbf{B} + \mathbf{E}_{AD}),$$

with

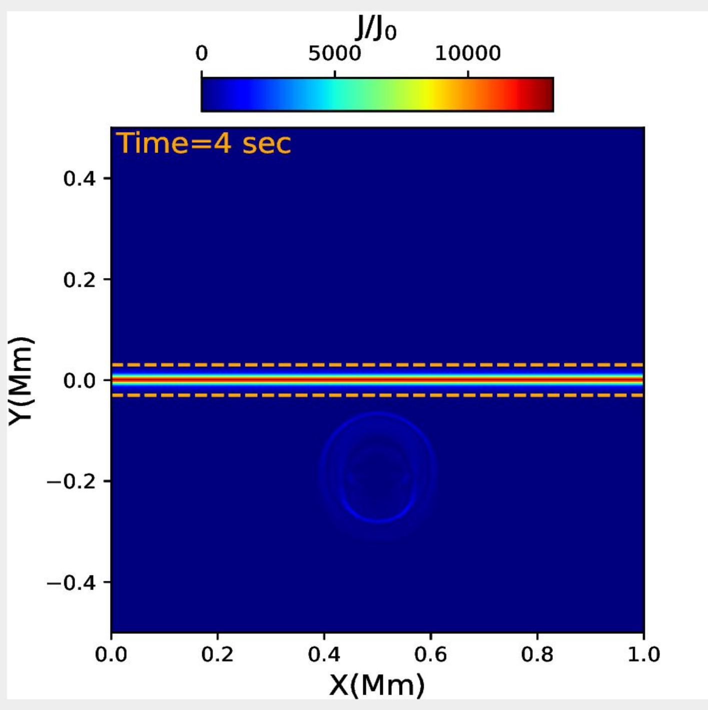
$$e = \frac{p}{\gamma-1} + \frac{1}{2}\rho|\mathbf{v}|^2 + \frac{1}{2\mu_0}|\mathbf{B}|^2$$

(iii) In our model, we have taken a horizontal Harris current sheet configuration under chromospheric condition with density (**ρ**)=**1.66×10^{-10} g cm^{-3}**, temperature **(T)=10^{4} K**, ambipolar diffusivity (**η_{AD}**)= **10^{5} cm^{3}s g^{-1}** and magnetic diffusivity (**η**)= **1.27×10^{8} cm^{2} s^{-1}**.

$$B_x = -B_0 \tanh\left(\frac{y}{l}\right)$$

$$B_y = 0$$

$$B_z = B_0 \mathrm{sech}\left(\frac{y}{l}\right)$$



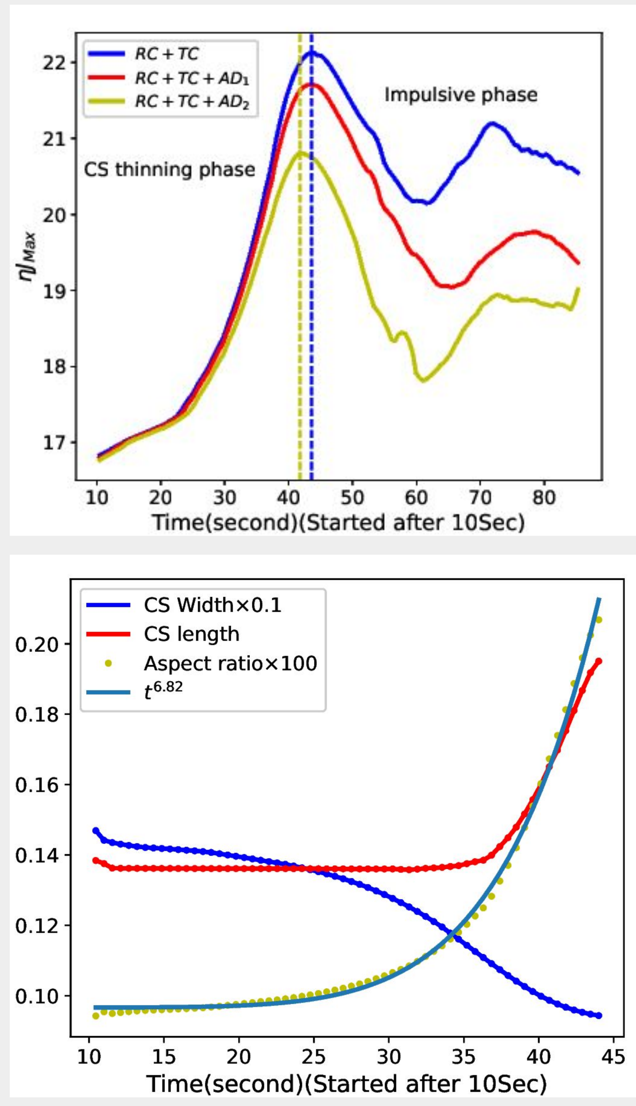
(Fig 1: Current sheet configuration)

- After considering initial magnetohydrodynamics equilibrium, we have perturbed the CS with the velocity pulse, which is given below,

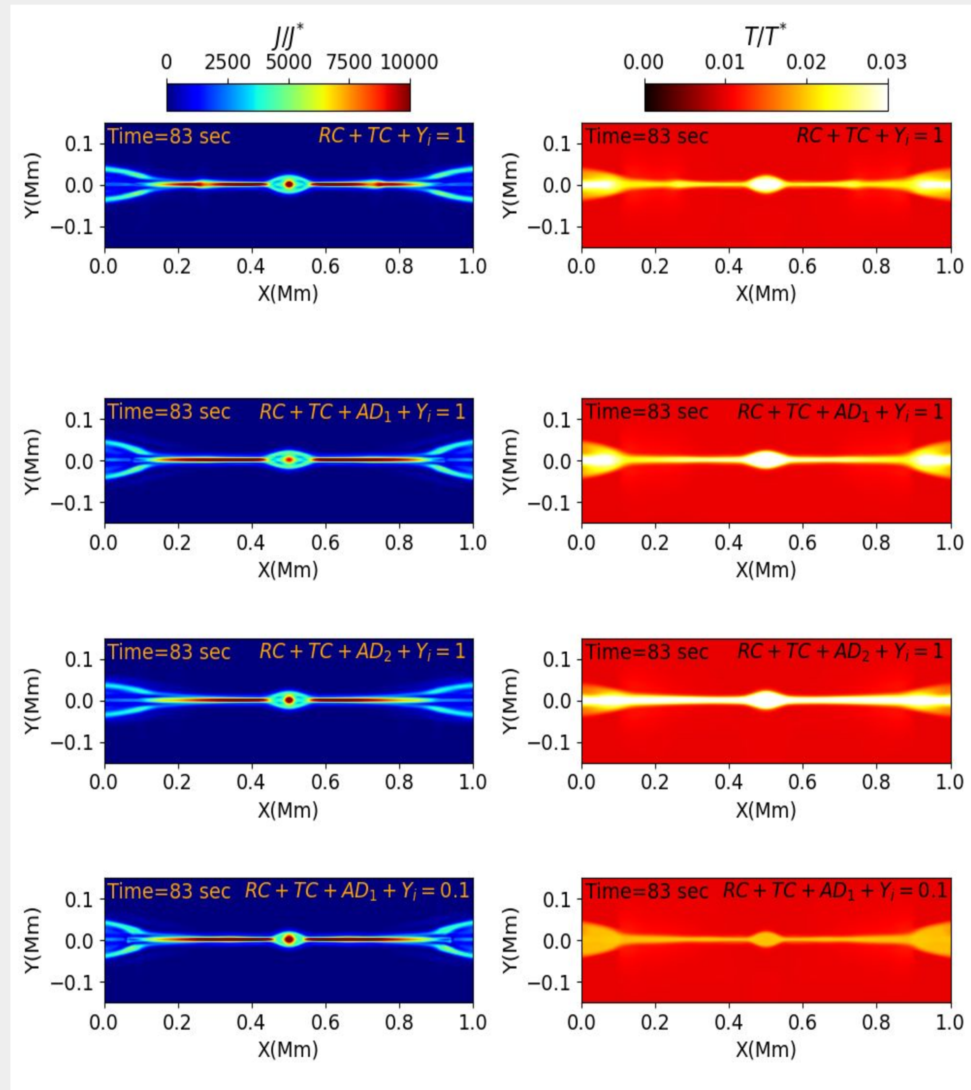
$$v_y = v_0 \exp\left(-\frac{(x-x_0)^2 + (y-y_0)^2}{w^2}\right)$$

B_0=82 G, l=30 km
v_0=45 km/s, w= 10 km
(x_0, y_0)= (0.5, -0.2) Mm

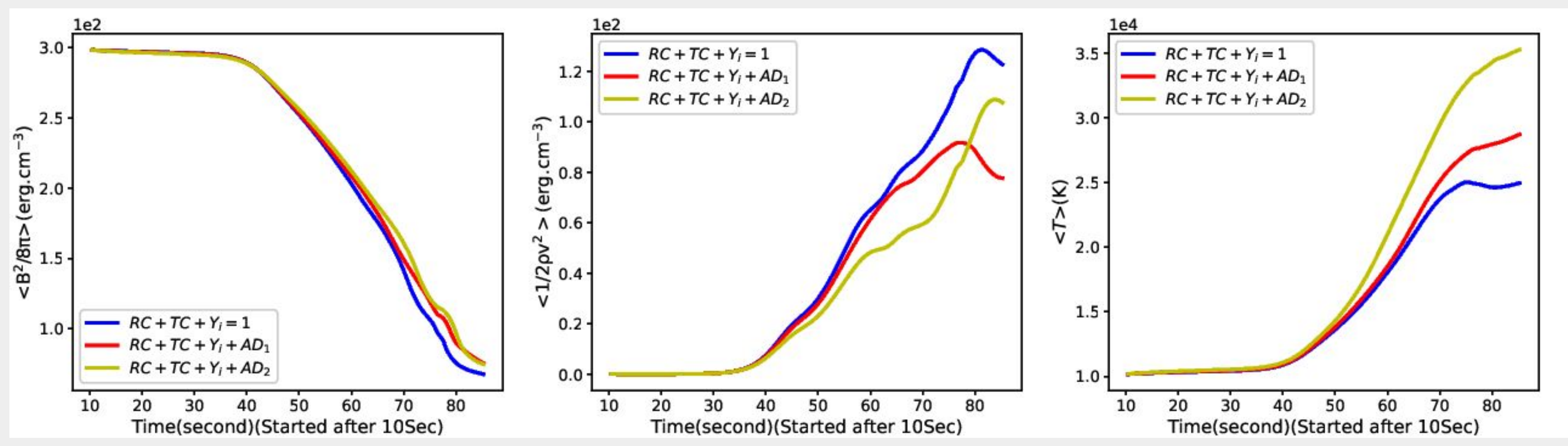
Results



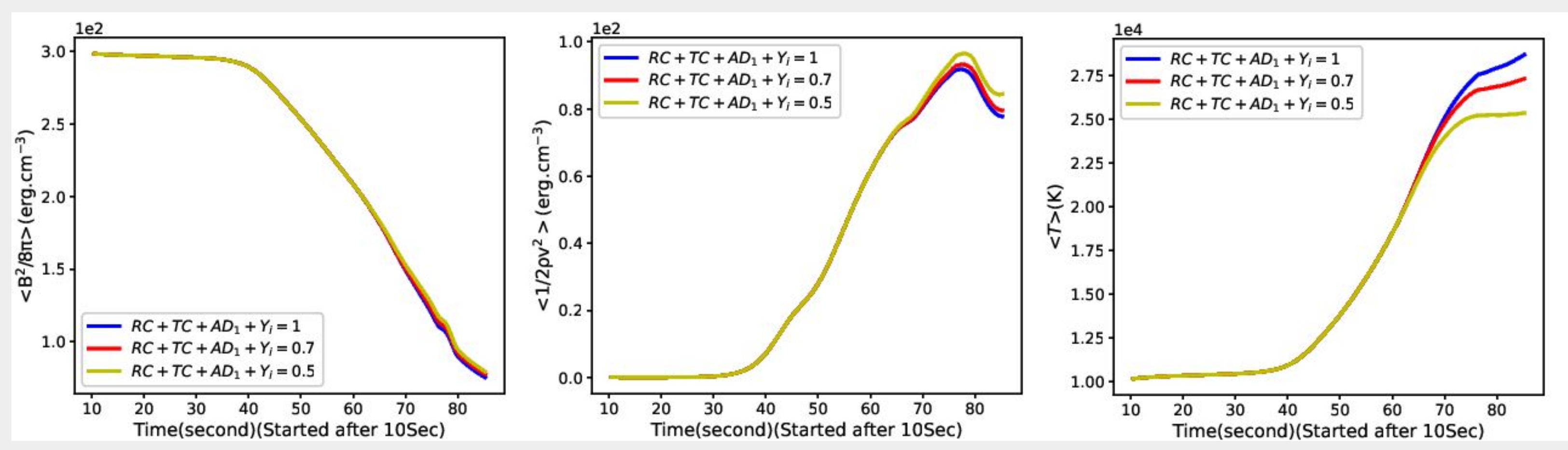
Reconnection rate and thinning profile



Current density and temperature profile map under different AD and Y_i



Magnetic energy, kinetic energy and avg temperature profile around the CS with different AD at the time of magnetic reconnection.



Magnetic energy, kinetic energy and avg temperature profile around the CS with different ionization fraction at the time of magnetic reconnection.

Conclusions

- Under chromospheric magneto-plasma condition the reconnection rate is always in **Petchek regime** with time exponent 4.06.
- Also due to the **presence of ambipolar diffusion, reconnection rate is decreasing as the temperature and pressure of the CS is increasing**. But for different ionization fraction, no significant change is observed.
- The out-flowing plasma speed is in the range of **2 to 20 km s^{-1}**, which is equivalent to the cool chromospheric jets speed in the chromospheric level. The temperature of the out-flowing plasma can reach **3.6×10^{4} K**.

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