CALCULATION OF THE INTERACTIONS BETWEEN SOLAR WIND PARTICLES AND COMETARY ION TAIL

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ABSTRACT: *The physical properties of the interaction region between the solar wind and comets were studded by solution of the continuities equations using first-upwind explicit method in three dimensions. The cometary ion tail formed and shaped due to the existence of the interplanetary magnetic field (IMF) which depending on the comet type has also been made. The physical properties and its change for comets studied in this research are: mass density, velocity and magnetic field for the comet's ion tail. In this research, simulations of the interaction between solar wind and cometary ions are performed using the MHD laws. The simulations included in the present research cover two general cases (without source term where the solar wind properties are studied when there is no comet) and (with source term, in the presence of the comet). Also the effect of interplanetary magnetic field on the solar wind and cometary tail interaction has been studied in both cases. In this research, the continuity equations were solved in one and three dimensions using the First-Upwind explicit method, the results of the present research showed that the interaction near the cometary nucleus is mainly affected by the new ions added to the plasma of the solar wind, which increases the average molecular weight and result in many unique characteristics of the cometary tail. These characteristics were explained in the presence of the IMF.*

Keywords: Magneto-Hydrodynamic (MHD), First-Upwind, Interplanetary Magnetic Field (IMF), Explicit Method.

1. INTRODUCTION

MHD is the study of electrically conducting fluids, combining both principles of fluid dynamics and electromagnetism. The subject of MHD is traditionally studied as a continuum theory, that is to say, attempts at studying discrete particles in the flows are not at a level such that computation in these regards is realistic. To run “realistic simulations” would require computations of flows with many more particles than current computers are able to handle. Thus, the only way to study MHD seems to be in its continuum form- leading us to its description using the continuity fluids equations [1].

Another important aspect that underlines the importance of numerical modeling is that space experiments are of an observational nature, and we cannot control the conditions of the system under study. Reproducing a system’s behavior, and measurements thereof, in numerical tests is therefore critical to identify laws governing the system [2].

The existence of the solar wind was not conjectured until the latter half of the past century. The first hints of the wind’s existence came from observations of comets’ ion tails Biermann in 1957 argued that solar radiation pressure was not enough to explain the acceleration of plasma structures within comet tails. We now know that the solar wind not only dictates the orientation of cometary ion tails, but also directly influences their rapidly-changing morphologies [3]. The solar wind is a bimodal stream of fully ionized, electrically neutral, fast plasma; its two states distinguished by their velocities, particle temperatures, density and composition, which vary with both time and space. A close correlation between the composition of the solar corona and the solar wind indicates that it is an extension of the hot solar corona that expands radially outwards into the solar system. Due to the extreme temperature and energies in the outer corona, the solar wind’s velocity reaches supersonic levels a few solar radii above the solar surface. This continuous outflow of collision less solar plasma carries with it a remnant of the solar magnetic (B) field, known both as the interplanetary magnetic field (IMF) and the heliospheric magnetic field (HMF) that pervades interplanetary space [3]. The interactions between solar wind particle and cometary ions have been studied progressively since 1951 .Solar wind consists of plasma, which includes a wide variety of ions, free electrons as well as gamma rays, emerged within the Interplanetary Magnetic Field (IMF).

Comet tail, on the other hand, consists of heavy ions and free electrons only. The plasma tail of the comet is totally shaped by the flow of solar wind facing the moving comet. Its shape is sensitive to any changes in the solar wind properties (density and temperature) as well as the changes in the IMF, thus comet tail can be used as a probe to study solar wind parameters as well as the structure of the IMF. At one astronomical unit (1 AU), the average speed of the solar wind is around 400 km/s. The solar wind average density at such a distance is approximately 7 protons/cm^3. Most interesting changes in the comet tail are disconnection events, which are thought to occur during crossing IMF sectors. The role of IMF is thought to be an important factor in shaping the comet tail [4]. Computer simulation has been used extensively to study the solar wind – cometary tail ions interactions since it is the only fruitful method that could be used with ease. With the availability of data collected from the spacecraft missions, computer simulations have more importance to analyze these data. There have been many simulation attempts that showed many important features of the interaction process. Thanks to the progress in computer ability to handle more complicated calculations, computer simulation is now a very important source to better understanding the interaction process [5].

2. Composition of Comet

Briefly, a comet consists of a clear nucleus, of ice and rock, surrounded by a cloudy atmosphere called hair or comma. The American astronomer Fred L. Whipple described in 1949 the nucleus of the comets, that contains almost all the mass of the comet, as "dirty a snow ball" composed by a mixture of ice and dust [6]. The radicals, for example CH, NH and OH, come from the breakage of some of stable molecules CH4 (methane), NH3 (ammoniac) and H2O (water), that can remain in the nucleus like ice or like composed more complexes and very cold. Another fact that supports the theory of the snow ball is more that it has been verified, in observed comets, than their orbits are turned aside enough of the anticipated ones by the Newtonian laws. This demonstrates that the gas escape produces jet propulsion that slightly moves the nucleus of a comet outside its trajectory, on the other hand, easy to predict. In addition, the comets of short periods, observed throughout many revolutions, tend to vanish with time as it could be expected of those of the type of propose structure by Whipple. Finally, the existence of comet groups demonstrates that the cemetery's nuclei are solid units [7].

3. The Magneto-Hydrodynamics first-upwind model (MHD):-

The state of plasma with mass density (ρ), number of particle (n), Momentum (q), pressure (p), velocity (υ) and magnetic field (B) at ***x-direction*** and time ***t*** is determined by the conservation law of general MHD. The equations of the ideal MHD describe the dynamics of plasma under the influence of a magnetic field, and are given by [6]

3. Conservation of mass density (ρ):

The conservation of mass density is written as [8]

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho v) = \rho_c^{\cdot} \qquad (1)$$

Where $\rho_c^{\cdot}$ the mass source of cometary ions with ionization rate (σ), solar wind particles velocity (υ_c), distance from nucleus (r) and constant molecular mass (m_c) is giving by [5]:

$$\rho_c^{\cdot} = \frac{G\sigma m_c}{4\pi r^2 v_c} e^{-\frac{\sigma}{v_c} r} \qquad (2)$$

3.2. Conservation of particles number (n):

Because of the production of heavy cometary ions the mean molecular weight varies throughout the cometary atmosphere. To determine ion, proton and electron densities as well as ion temperature the equation of continuity must be solved for the particle number density (n) [8]:

$$\frac{\partial n}{\partial t} + \nabla.(nv) = n_c^{\cdot} \qquad (3)$$

The source term $n_c^{\cdot}$ takes in to account the production of particles by photoionization and electron impact ionization; recombination removes particles from the plasma. In the ideal model [5]:

$$n_c^{\cdot} = \rho_c^{\cdot}/m_c \qquad (4)$$

Where m_c represents the constant molecular mass with typical value $m_c = 20 m_p$ (m_p is the proton mass) [8].

3.3 Conservation of velocity (u):

The conservation of velocity is written as [8]

$$\frac{\partial u}{\partial t} - v\nabla v + \frac{1}{\rho}\nabla P + \frac{B}{4\pi\rho}\nabla B = 0 \qquad (5)$$

The source term in this equation is neglected because it contributes with ~ 2% to the equation [8].

3.4 Conservation of magnetic field (B):

The conservation of magnetic field is written as [9]

$$\frac{\partial B}{\partial t} = [\nabla \times [v \times B]] \qquad (6)$$

3.5 Conservation of pressure (P):

The conservation of pressure is written as [9]

$$\frac{\partial P}{\partial t} + v\frac{\partial \rho}{\partial x} + \gamma\rho\frac{\partial v}{\partial x} = P_c^{\cdot} \qquad (7)$$

Where

γ: Specific heat ratio.

$P_c^{\cdot}$: The pressure source term, this related to the internal energy source term (e_c) and is giving by [8]:

$$e_c = \frac{1}{2}\rho_c^{\cdot} v_c^{\cdot 2}$$

4. The interaction between the solar wind and cometary nucleus.

The numerical results which have been obtained from the present numerical simulation will be presented. One and three dimensional MHD system was assumed to simulate cometary plasma interaction with solar wind interaction is described by the main conservation laws (equations (1) to (6)). .The continuity equations of a magneto hydrodynamic system have been used to study the interaction of cometary ions of the tail with solar wind. This interaction describe by described by the MHD system. This system of partial differential equations can be numerically solved using a particular method, which in this case was first-upwind explicit method. This method is assumed of better accuracy than other explicit methods such as Leap-Frog explicit method, yet implicit methods are considered of better accuracy. However, explicit method is preferred when taking the programming effort into consideration. The methods have been used is explicit methods based on the first-upwind difference scheme**.**

The explicit simulation has been performed for one and three dimensional space. The programs used in the current research were all written using the **(MATLAB 7.0)** programming language.

Table (1): The physical properties of comets that used in this research [10], [11].

Comets	*Mass* *M (Kg)*	*Radius* *R (Km)*	*Mass density* *ρ* (gm/cm^3)	*Production rat* *G (molecules/s)*
Halley	2.2 ×10^{14}	7.4	0.2 - 1.5	6.9 × 10^{29}

5. Source Term Effect

In the present study, simulation was considered for case of source term and without source. When the source term was added the results showed more stability for explicit simulations. The source term added a considerable effect in the beginning of the mesh, where the cometary nucleus is assumed to exist. Source terms are found in the equations of particle density, ρ, (and hence number of particles, n_p), velocity, v, and other properties as will show.

Since the source term of the velocity depends on the charge exchange then the source term of the continuity equation of velocity effect is less than ~ 1%, therefore it is ignored during the calculations. The continuity equation for the magnetic field does not contain any source term. Only source terms for density were considered.

If the source term is required it was summed directly with the right – hand side of continuity equations. And when it is not needed (in the cases of no source), the source term value was set to be zero, acting as (no source) to the scheme.

6. Initial and Boundary Values Effect

The computer programs used in the present study have a set of initial and boundary conditions, that are required to setup the physical properties of the system. These initial and boundary values determine the starting and ending points of the results, but not the behavior of the system, and if these values were chosen wisely within the logic limits of case under study.

Table (2). Initial and boundary conditions adopted in the present research.			
Parameter		**Initial**	**Boundary**
Mass density	ρ	1.8	**150**
Particles velocity	v	0.0001	**0.1**
Magnetic field	B	0	**4.5**
Pressure	**p**	**4×10^{-9}**	**4.0×10^{-9}**

The values of the comet's physical properties calculated in this work are:

1. Mass density, ρ, from equation (1)
2. Particle velocity for three components, viz. u_x, v_y, w_z from eq. (5).
3. Magnetic field for three components, viz. B_x, B_y, B_z from eq. (6).

The physical properties of the system used in these programs are shown in Table (3)

Table (3). Cometary and solar wind characteristics used in the present work. [8]

Gas production rate *G*	**6.9×10^{29} sec^{-1}**
Gas production rate *G*	**$20 \times m_p{}^{*}$ kg**
Constant molecular mass m_c	**10^{-6} sec^{-1}**
Ionization rate □	**1 km sec^{-1}**
Molecular velocity v_c	**$5 \times m_p{}^{*}$ kg cm^{-3}**
Solar wind density □□	**400 km sec^{-1}**

* m_p = proton rest mass = 1.667×10^{-27} kg.

7. Numerical Results:

In this section the results of physical properties of comet with gas production rate (G) shall be presented as shown in table (3):

7.1. RESULTS OF HALLEY COMET:

The results of physical properties of comet Halley are shown in Figures ((1) to (6))

7.1.1. Results and Discussion of One Dimensional magneto hydrodynamic explicit simulation

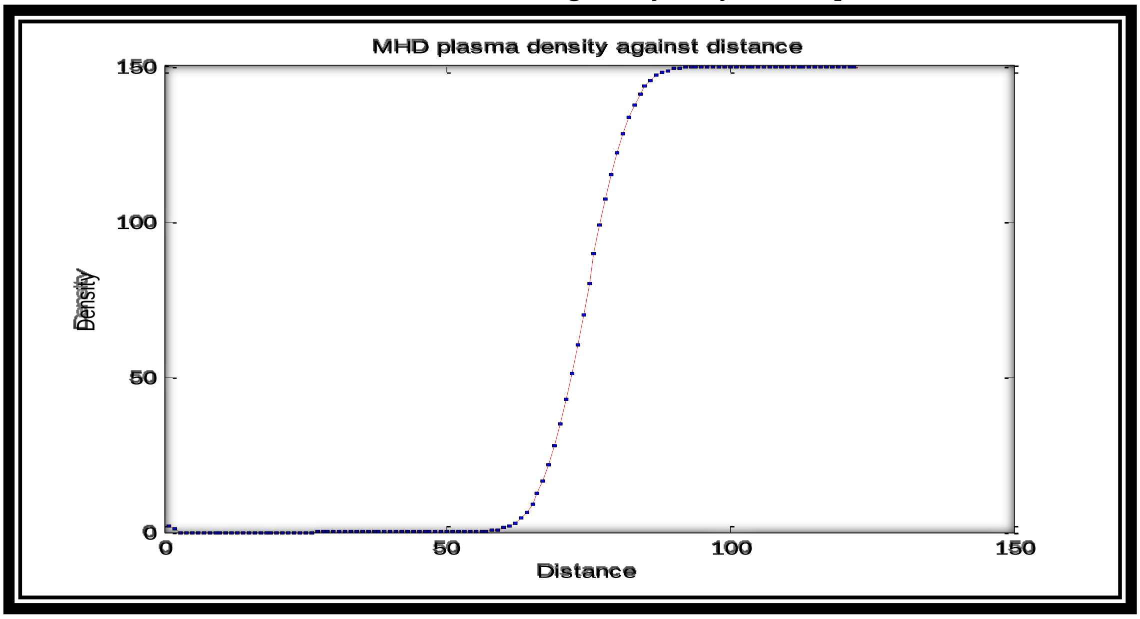

Figure (1): Relation between density and number of particles for one –dimensional magneto hydrodynamic simulation and space, using first-upwind explicit method, without source term.

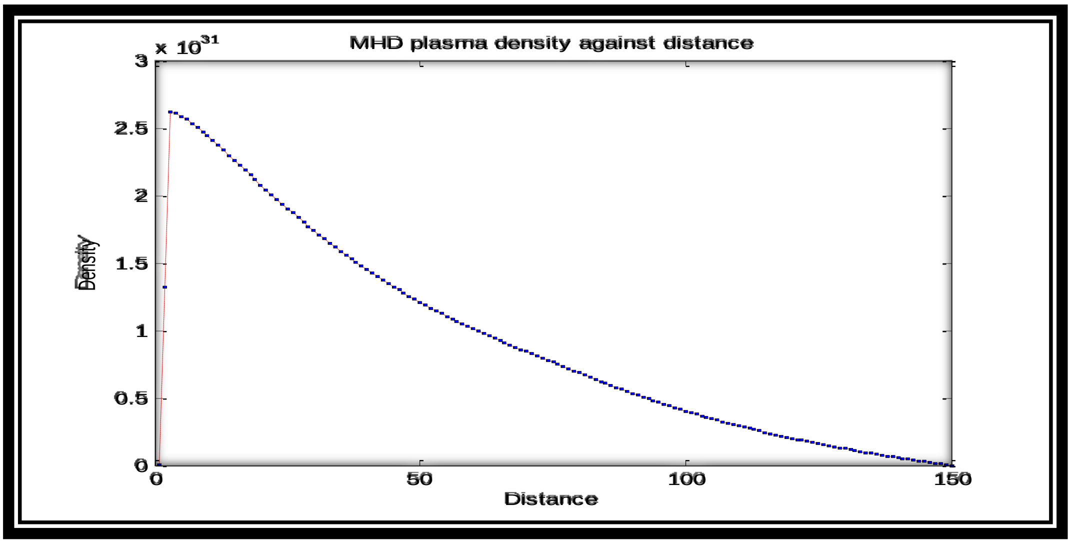

Figure (2): Relation between density and number of particles for one –dimensional magneto hydrodynamic simulation and space, using first-upwind explicit method, with source term.

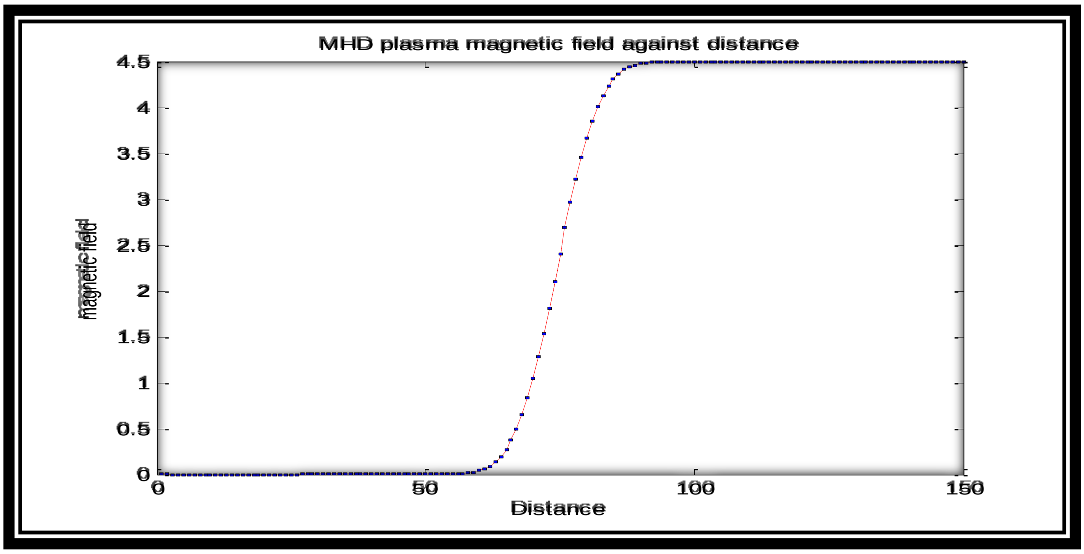

Figure (3): Relation between magnetic field for one – dimensional magneto-hydrodynamic simulation and space, using first-upwind explicit method, no source.

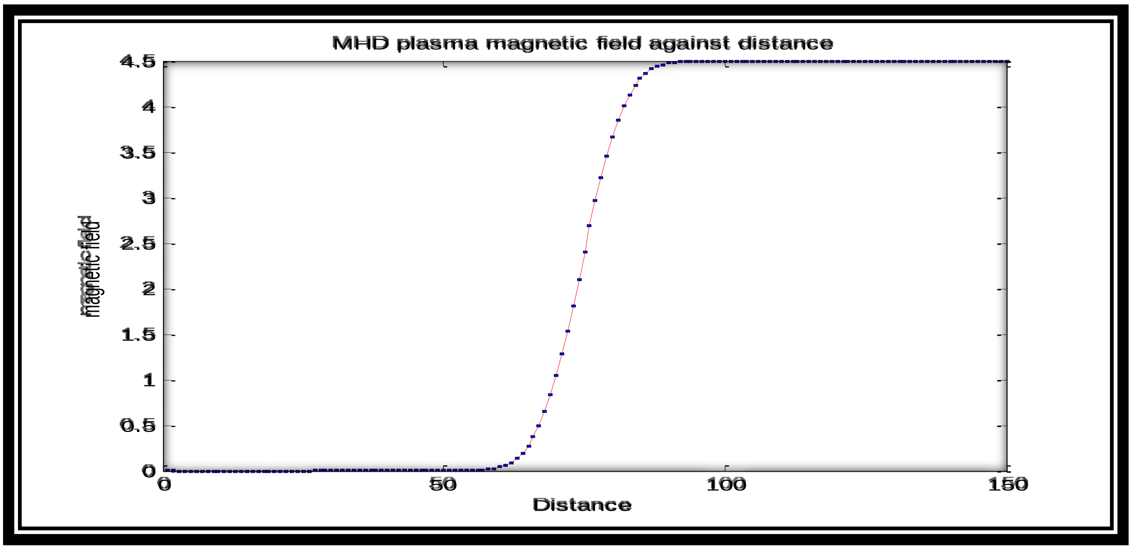

Figure (4): Relation between magnetic field for one – dimensional magneto-hydrodynamic simulation and space, using first-upwind explicit method, with source.

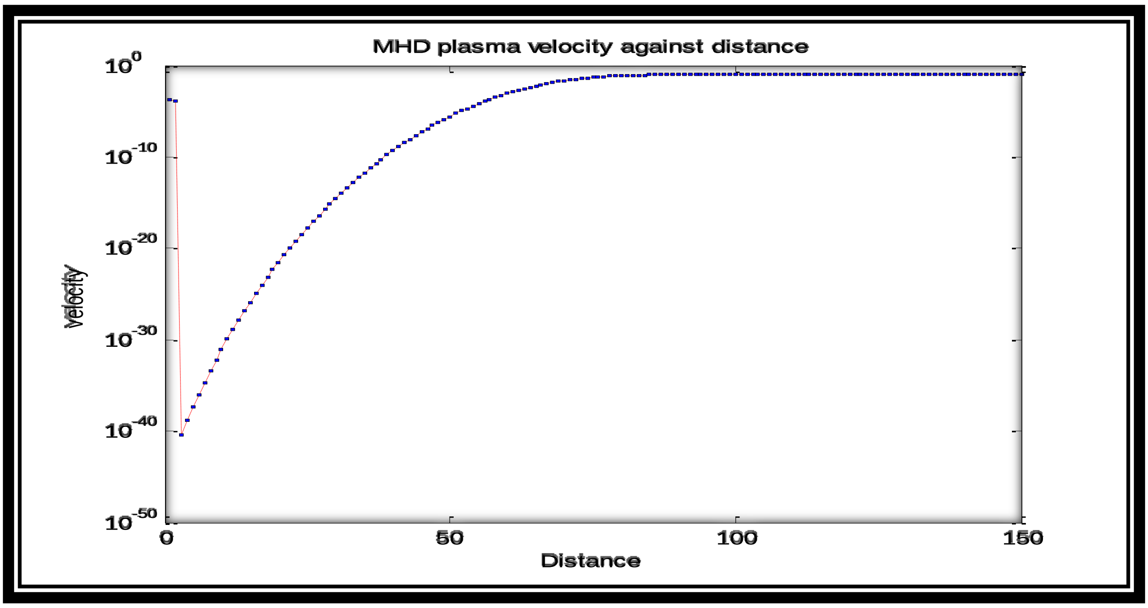

Figure (5): Relation between velocity for one – dimensional magneto-hydrodynamic simulation and space, using first-upwind explicit method, no source.

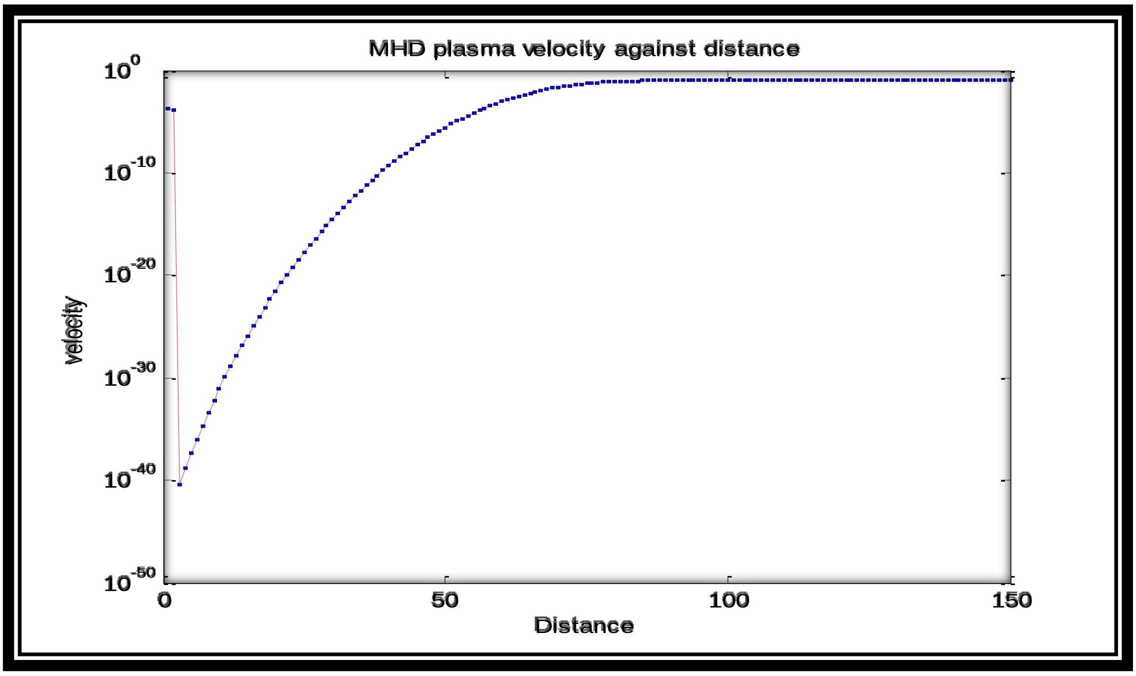

Figure. (6): Relation between velocity for one – dimensional magneto-hydrodynamic simulation and space, using first-upwind explicit method, with source.

The results of Figures (1) represent the density of one – dimensional simulation without source and can be attributed as an increment in the mass density as the distance from the origin increases. Possible reason behind this effects is that the magnetic field pressure that acts on the plasma decreases as the distance increases. For the case of no source the effect of the ions produced from the cometary nucleus is ignored and the system is describe as an ideal system with no mass flow.

Figure (2) show result for density of one – dimensional simulation with source. In this case, the addition of new particles to the stream of solar wind will result in a sharp increasing near the cometary nucleus .when the solar wind stick the comet nucleus result to generation new ions added to the solar wind. As the distance increases from the nucleus. There is a gradual decrease in the particle density.

The effects can also be seen from the results of Figure (3) to (6) where the particles velocity has same acts in the both case with source and without, the same as the magnetic field, the reason behind that Since the source term of the velocity depends on the charge exchange then the source term of the continuity equation of velocity effect is less than ~ 1%, therefore it is ignored during the calculations. The continuity equation for the magnetic field does not contain any source term. Only source terms for density were considered.

7.12. RESULTS AND DISCUSSION OF THREE DIMENSIONAL MAGNETO HYDRODYNAMIC EXPLICIT SIMULATION

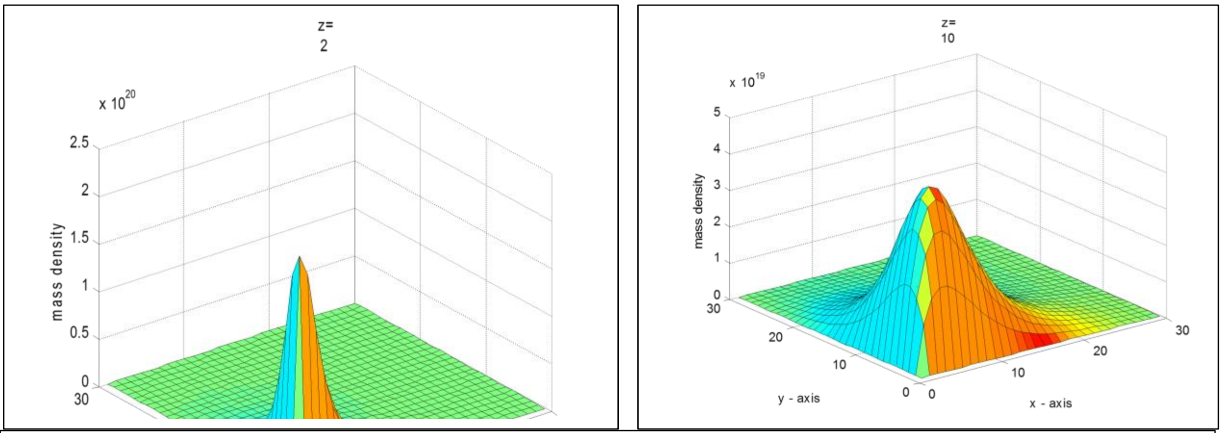

Figure (7): Relation between mass density (amu.cm^{-3}) of Halley comet for three-dimension magneto-hydrodynamic (MHD) simulation and space, using first-upwind method.

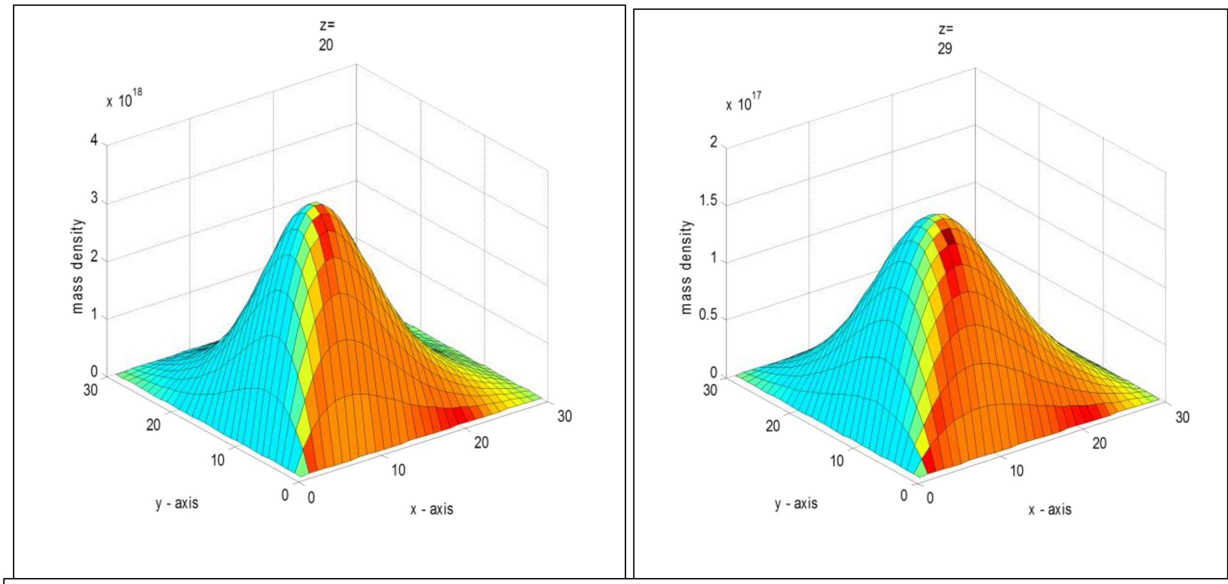

Figure (8): Relation between mass density (amu.cm^{-3}) of Halley comet for three-dimension magneto-hydrodynamic (MHD) simulation and space, using first-upwind method.

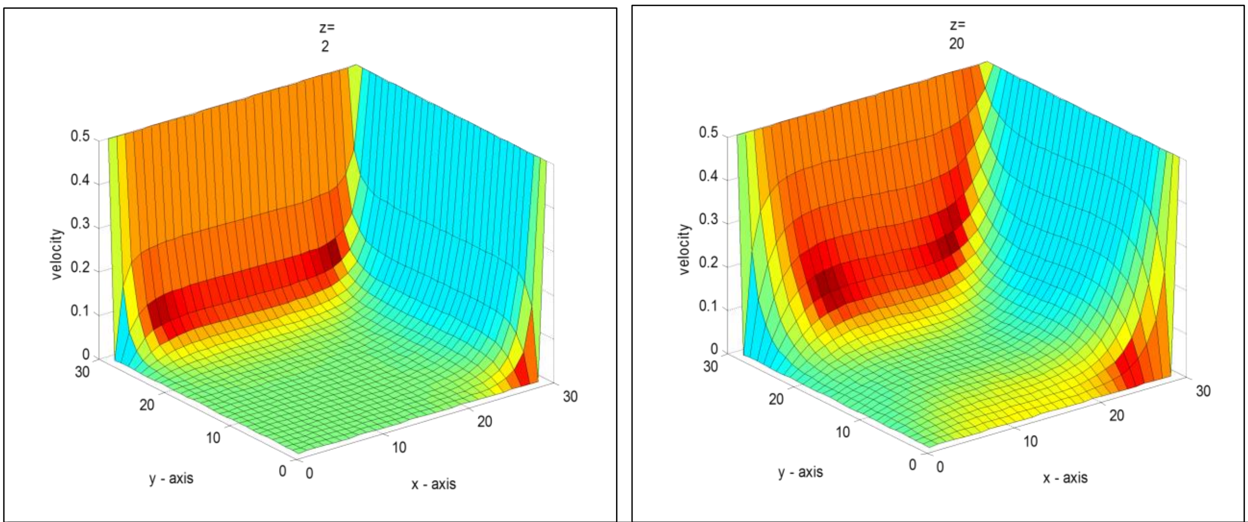

Figure (9): Relation between velocity (km.s^{-1}) of Halley comet for three dimension magneto-hydrodynamic (MHD) simulation and space, using first-upwind method.

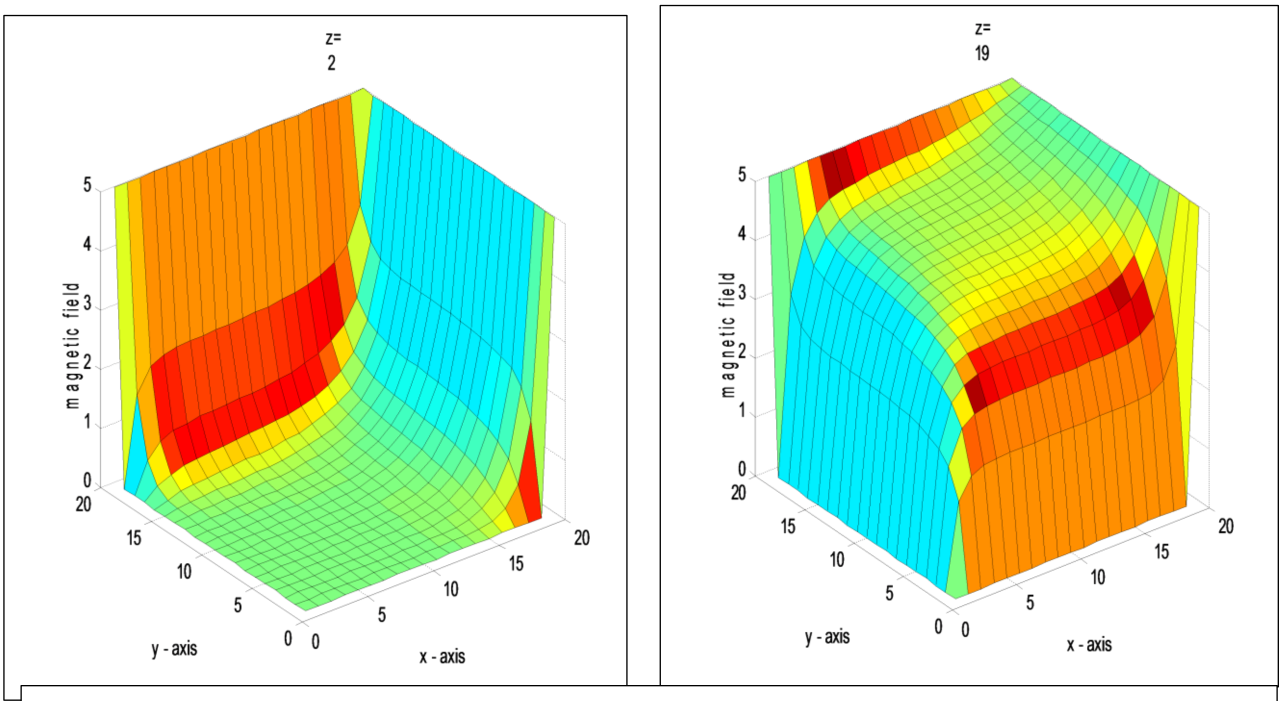

Figure (10): Relation between magnetic field of Halley comet for three-dimension magneto-hydrodynamic (MHD) simulation and space, using first-upwin method.

From the law of mass density conservation equation (1) its contain the source term (ρ_c) it's the density present from added new ions to the plasma this ions generated from comet nucleus, has been used in order to calculate the mass density of comet and it found that its value increasing in the interaction region between the solar winds particles and cometary ions which is formed in front of the cometary nucleus. From figure (7), (8), it's found that the peak was $\simeq 2.5 \times 10^{20}$ at z =2 and become $\simeq 5\times10^{19}$ at z=10 then $\simeq 4\times10^{18}$ at z=20 and $\simeq 2\times10^{17}$ at z=29 where z represent the distance outward from the nucleus.

Then figure (7), (8) shows the results of the density for the case of source. From this figure it is seen that the source effect with increasing the z-axis is that the peak decreases as the z-axis increases, This indicates that the mass density decreases considerably as the values of the z-axis increases, which is as expected since elevation of the z-axis means more distance from the source (the cometary nucleus).

Figure (10) represent the component of magnetic field as deduced from explicit simulation. Since the continuity equation of magnetic field has no source term. Then the component of magnetic field it remains almost the same in all points as in the case of the source and the state of the absence of the source. In comparison with the source number [4] similar behavior was reached, In all previous results by other researchers

The same behavior of the magnetic field components with the velocities is explained as due to the effect of the magnetic pressure [4] where the charged particles of the plasma are confined within the interplanetary magnetic field, and the mobility of these particles is greatly affected by the strength of the magnetic field. So we see the speed components are the same at all points and in both cases as show in figure (9).

8. CONCLUSION

Study of the mass density variation with space, the conclusion mad here is that the ions destiny reaches the maximum at close distance to the cometary nucleus. This is joined with increment in the number of particles.

The first-upwind method has a higher (second) order of accuracy and it simple, stability and more accuracy from other approximations. Therefore, it has been used in the present research.

9. REFERENCE

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