Applying differential equations for study magnetohydrodynamic phenomenon on the solar surface

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Abstract. The aim of this research is to study the magnetohydrodynamic (MHD) phenomenon on the solar surface by apply differential equations. We are trying to understand and explain the processes from observable solar layers to deeper layers, by using plasma theory and data analysis that may construct understandings to solar physics. This research is done by combining the MHD simulation and data of solar observation results. MHD simulation was carried out in the theoretical laboratory, physics department, UM. Data on the sun’s observation were obtained from LAPAN Watukosek Jawa Timur. The results of this study are the coronal solar helmet streamer structure is degraded and the MHD equilibrium ends before it erupts. This is shown by the simulation results using data obtained from observations, namely the degradation of colors from the strongest to the weakest. This shows the existence of weakening energy before finally experiencing an eruption. The phase was terminated by the coronal mass eruption (CME). Activity to the surface of the corona to the inner layer is outside our technology to observe directly. Therefore, the conclusions in this article are made using the plasma flow approach at high temperatures.

1. Introduction
Our Sun is just a small part of the unlimited universe. The theory of elementary particle physics explained the creation at least through seven epochs before the Earth was formed and inhibited. They are space and time creation, energy injection into space-time, asymmetric and distinction of primitive matter and fields, Galactic cluster formation with purely primitive Hydrogen atoms, individual Galactic formations; stars, and solar systems formations; Planets, Planetoids, comets, and exo-planets formations [1]. Therefore, the sun is not unique in the universe and the material building blocks of the sun are similar and usual as in many stars and other solar system ingredients. The sun is a big ball of plasma; it
consists of primitive hydrogen, in the sub-atomic state, that is the population of hydrogen nucleus within free moving electrons in nearly water density. In some height, in a relatively cool layer (T=6,0000K), above the Sun’s surface (h~500 km), the Hydrogen nucleus might form Hydrogen in the Balmerian state. Other layers are difficult to have a chance the Hydrogen forming the state. The Sun in that extends may consider as giant magnetized plasma fluids in slow motion, but deposited huge energy excess.

The slow-motion of plasma fluid has generated a domain of special plasma physic for the Sun. It is termed as the magneto-fluid solar physics. In this domain, the magnetic fields, the mixed fluids of hydrogen nucleus and electrons, formed intimate relations to confine energy flow in special magnetic configurations called the sunspot region \[2\]. Then, we may term sunspot region as an active region, since the slow-motion on trapping energy flow in sunspot will turn to be place energy. It is released energy and propagated into interplanetary space with devastating effect. The sub-atomic plasma and the magnetic field always co-exist and co-influence each other just like they are mutually frozen-in, for then they are frequently termed as magneto-fluid. Depends on how dynamic is the situation, the magneto-fluid notion might term as magnetohydrostatic or magnetohydrodynamics \[3\].

Both in magnetohydrostatic (MHS) and in magnetohydrodynamic (MHD) physics for solar hot plasma, the formalism for displacement current like in solid conductor is neglected. Consequently, the magnetic field and its inductive magnetic fields are equally the same creature and symbolized by the usual symbol in physics as \(B\). Since the magnetic fields and the plasma frozen-in to each other, the dynamics in magneto-fluid are the dynamics of the magnetic fields and the plasma as well. Deviation from the frozen-in principle is assumed only when a special process called magnetic reconnection to occur \[2\]. This process might occur in solar layers to planet proximity space. In the deep solar layer, the process is often termed as the solar magnetohydrodynamo (MHDo). The process plays an important role in generating and accumulating gigantic energy from the solar differential rotation process at convective layer depth. All of those physics lies in the domain non-linear mathematics and best represents time-dependent differential equations. These equations expressed in form as follows \[4\].

\[
\begin{align*}
\frac{\partial}{\partial t} \rho + \nabla \cdot \rho \vec{V} &= \varepsilon \nabla^2 \rho + 0 \quad \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdot
2. Methods

Observations to solar from the surface down to inner layers are beyond our technology to observe directly. In this research, we infer from the physics approaches of fundamental water-density high-temperature plasma. Hardware and technology to grasp data and to study the MHS, MHD, and MHDo processes on the solar surface down to our planet-proximity, heavily depends on solar telescopes. Therefore, we are involved in an up-graded software system for the general Solar-Earth based coordinate system with the new tensorial coordinate system which applies the Einstein-summation rule. It is similar to operational algebra in general relativity physics. By this method, the results look more complete in coding and accurate in computing; and easy displaying the results in solar surface geometry; as well as for handling and drawing the outputs from MHD numerical simulations. Then, we utilized more physics cases rather than statistics and even more tried to utilize the results from MHS, MHD and MHDo research did. While the statistic method gives rough estimation for warnings, the new method gives more accurate and acceptable physics.

A combination of the data from the telescope system with the YOHKOH solar soft X-ray satellite to study magneto-fluid in the MHD force-free approach has been done. Simpler telescope built at Watukosek in East Java, Indonesia, to patrol the solar flare at Balmer line and to patrol the sunspot or at the white-light patrol. Later, as our team had appreciably data compilation from the solar sunspot and Hα flare, then we tried to explore the physics of interactions before, during and after Hα flares events. The solar Hα flare observations on solar chromospheric layer used narrowband filter, in Balmerian Hα line (λ=6,562.8 A˚) [4]. This research used the Ritz method and utilized the finite element method to have a numerical solution of the magneto-fluid transport phenomenon and compare the results with observational data.

3. Results and discussion

MHD transport phenomena are relatively observable and accessible on the solar surface rather than the MHDo transport phenomenon in the convection zone. There is a lot of solar surface phenomenon can be used to justify the MHD theory [6]. Moreover, there are many transport phenomenon can be approximated by ideal MHD and for some fast transport, the phenomenon may still be best approached by adiabatic energy transports.

The solar surface MHD transport phenomenon is in low beta plasma like in the solar corona, or it may be in unity beta plasma in the low solar chromospheric zone. In this circumstance, the ideal MHD is a good approach since the physical environment is almost ideal. In the solar corona for instance, the situation is controlled by the slow magnetic evolution in very rarefied plasma, such that the mathematical analytical solution of MHD expressions almost matching with the observational data. Only in special cases, the analytical solution does not match with the observational data, and another approach (i.e. numerical approach) is needed to accomplish the problem [7]. For example, inactive flaring regions where a massive CME is about erupting.

Useful study to discover various physical interactions on the solar surface may be opened by assuming a quasi-static condition of magneto-fluid. By applying equation (2) and considering that relative motion is very small (\(V \approx 0\)) such that some terms will be diminished. We may write the source function \(S\) as follow

\[
S = -\nabla P + (\nabla \times B) \times B + \rho G
\]

Equation (5) is usually called as magneto-static or magnetohydrostatic (MHS) equation. Much study has been subjected to figure out the starting point of MHD transport phenomenon from this equation. These studies provide an objective way for investigating a realistic computational initial condition. If we assumed that \(A\) as magnetic potential function, then

\[
B = \nabla \times A
\]
Then, the expression for the MHS condition may be written as follow \[8\].

\[ \nabla^2 A + \lambda F = 0 \]

(7)

The hydrostatic pressure \(P\), magnetic field \(B\), density \(\rho\), and the passively solar surface gravitational acceleration \(G\) are absorbed into the function \(F\). The simplest configuration is the purely magneto-static or MHS initial condition, i.e. when \(\nabla^2 A = 0\) \[9\]. But on the solar surface, everything subjected the ever changes face including the magnetic field and plasma on the surface \[8\]. An initial purely MHS never exists in long time scale since the differential rotation of the sun and from the MHDo process will always interfere with the initial MHS to deviate away from \(\nabla^2 A = 0\). It means that equation (7) is more likely a realistic initial condition on the solar surface \[10\].

This research is to explain the solar surface MHD transport phenomenon. Solar surface energy is done through the analytical searching of equilibrium sequences of equation (7) by varying \(\lambda\) and to seek equilibrium lost for a certain magnetic topology included in \(F\). Many studies have also been created to seek equilibrium sequence by considering various magneto-fluids by trying to assume various \(F\), since this function still open for great variety models of magneto-fluid on the solar surface. Intensive and extensive discussions of the subject may be found in other articles \[4\]. Generally, the magneto-fluid on the solar surface evolutes through a series of equilibrium until it reaches critical equilibrium and may erupt or re-adjust to other sequences of equilibrium \[5\].

Using the ideal MHD of the GNLS equation \((f, \xi_1, \text{and } \xi_2 \text{ are zero})\) we simulated the coronal helmet streamer formation. In this research we simulate magnetic fields grow in the high corona by magnetic induction in presumable conductive coronal material when a large sunspot group in the photosphere is emerging and attains equilibrium subsequently \[7\]. The results show that a helmet streamer attains MHD equilibrium in 20 minutes or so. The helmet streamer preserves the MHD equilibrium in several hours or even in several days and may depend on the sunspot group evolution in the helmet’s footpoints. Disruption of a stable helmet structure may come from essential perturbation along with its footpoints or maybe from the sunspot group evolution \[11\]. In some events, the disruption of a helmet streamer will connect with other MHD fast transport phenomena such as the flares, two ribbons flares, and may initiate active prominence \[12\]. The coronal level observable MHD transport phenomenon is generally called the coronal mass ejections (CME).

![Figure 1. The result of the MHD phenomenon simulation.](image)

After a CME it may be a reformation of coronal magnetic fields to a new helmet streamer structure as the global open coronal magnetic fields close back down after energy release \[13\]. This may be interpreted from a theoretical point of view as losing equilibrium and going to other equilibrium sequences. It is still opened to investigate that the sequence may recurrently occur. Just like in the case of recurrent flares, it may be a coronal response to follow the lower solar atmosphere recurrent phenomenon. Simulation of the MHD transport phenomenon in loop flare has been conducted. The result of the simulation of the MHD transport phenomenon to solar surface showed in Figure 1. The
density structure evolution of the solar coronal helmet streamer and the final MHD equilibrium onset before erupting as a CME. Instead, we infer from the physics of fundamental water-density high-temperature plasma approaches

The simulation assumed a flux tube geometry model of sunspot magnetic fields in two dimensions. The magnetic flux tube has the capability to direct plasma flow from both footpoints to flow inside and along the loop. As time proceeds, more plasma will be trapped and plasma density increases non-linearly. The plasma density is going denser and mechanical friction among plasma particles is growing exponentially [3]. The sunspot magnetic flux tube may erupt subsequently and leaves a signature of foot-points remnant.

From MHD transport simulation, a solar CME may erupt by solely an intensive pressure perturbation, or by an extensive global shearing motion along with coronal magnetic fields. Other perturbations such as the global restructuring of coronal magnetic fields due to global saturated coronal magnetic fields are still in the preliminary stage [7]. Global saturation of magnetic fields may have resulted from slow but accumulative magnetic energy build-up from many solar surface-active regions. The number of eruptions of the CME due to the process may follow the sunspot activity cycle. Scientific adventure subjected to the study of the global solar coronal magnetic saturation theory is still widely open [2]. And other aspects of the dynamics of the solar coronal MHD transport phenomenon will be studied in other articles.

Another observational analysis of solar surface MHD transport phenomenon has been initiated [13]. They utilized data from YOHKOH soft X-ray and ground-based data from Mees Solar Observatory. The MHD transport perturbation occurred during the impulsive phase of a flare indicates a total displacement on the order of 1 arcsec. The apparent transport velocity exceeds typically reported sunspot proper motion in flare events. The result of the observation showed in Figure 2. The similarity of MHD simulation output with the realistic helmet streamer data image on the solar surface (from HAO).

Figure 2. The result observation MHD phenomenon to the solar surface.

4. Conclusion
Based on the discussion, it was concluded that the MHD simulation to demonstrate a loss of equilibrium in a coronal arcade may result in a coronal loop expansion and termed as the CME. This simulation has erupted prominence followed by a CME and subsequent re-arrangement to a new coronal structure. The Coronal Helmet Streamer is a consequence sunspot magnetic system in the solar active region at the coronal level since the corona is very conducive to the process. Therefore, other researchers in a similar theme, they are requested to other aspects of the dynamics of solar coronal MHD transport phenomenon.

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