Asian Journal of Information Technology 6 (2): 164-169, 2007

Design and Flow Simulation for a New DC pump MHD for Seawater

[1]N. Bennecib, [2]R. Abdessemed and [2]S. Drid
[1]Faculty of Science Engineering, University of Constantine, Constantine, Algeria
[2]Department of Electrical Engineering, University of Batna, Batna, Algeria

Abstract: In order to circumvent the corrosion and mechanical wear encountered on the mechanical parts, non-mechanical pumping systems have been developed to supplement the conventional mechanical ones. A complete set of basic equations for a new DC pump MHD to present a simplified MHD flow model based upon steady state, incompressible and laminar flow theory to investigate the characteristics of a new DC pump MHD is proposed in this article; finite volume method to solve both electromagnetic and hydrodynamic model under code DCPMHD. It is concluded that active part is necessary in the design of our pump; it indicated that the thrust performance depends on the electrode length and channel ray and appeared to favor L_2 = 0.08m, R_{ch}= 0.03 m as an optimized dimensions. The numerical results of the performance characteristic of a DC electromagnetic pump are discussed and shows that our new conception capable to delivering bi-directional activation.

Key words: Design, flow simulation, MHD, seawater, mechanical

INTRODUCTION

Magneto Hydrodynamic (MHD) covers researches on the generation of phenomena (such as stirring, mixing, separating and moving) under a magnetic action exerted on fluid. The utilization of MHD effects is multiple: among those, the MHD pump effect is one of the important effects. Contrary to the ordinary mechanical pump necessarily equipped with a rotary moving part like a blade, the MHD pump is notable for the complete absence of the blade-like part (Pei-Jen *et al*., 2004). To produce such an MHD pump effect, it is required from the pumping mechanism that the imposition of a constant magnetic field on a fluid which crossed by a DC current to create a fluid movement. Hence, these pumps are designed without using any movable part and thus are free of wear and fatigue problems caused by pressure-drop across the mechanical parts.

The Fig. 1 represents a new DC electromagnetic pump design. It consists of a magnetic in the torus shape, two winds, four electrodes and channel. It is assumed that fluid is an incompressible and laminar (Puush and Ira, 2002) and that material properties such as kinematics viscosity and density are constants (John, 2000; Yukihiro *et al*., 1996). The fluid in this case is seawater pure or "seeded" by NaCl to enhance the conductivity. In this study, a solution was obtained from both Navier-stokes and Maxwell equations under some assumptions which have acceptable physical meanings. From the fact that the parameter dependence of the DC MHD pumping effect became clear numerically and theoretically.

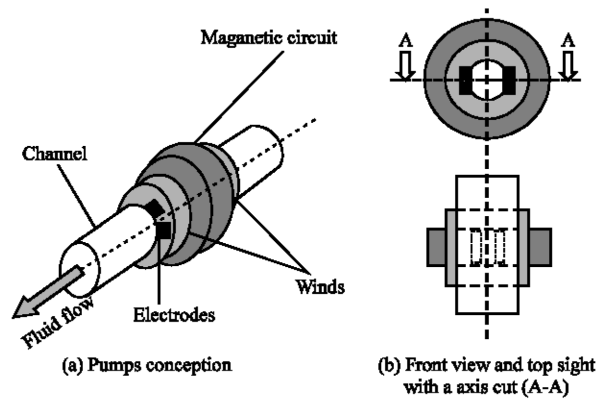

Fig. 1: Proposed DC MHD pump configuration

The present study shows the results of the DC pump MHD numerical simulation that we carried out. This pump proposed produces an axial flow. As a consequence, magnetic field can be obtained before calculating of flow field.

NUMERICAL ANALYSIS OF FLOW AND ELECTROMAGNETIC FIELD

The axisymmetric problem describing magneto hydrodynamic devices is obtained from the electro-magnetic equation in terms of the magnetic vector potential $\vec{A}$

$$\mathrm{rot}\left(\frac{1}{\mu}\mathrm{rot}\,\vec{A}\right)-\sigma\left(\vec{v}\wedge\mathrm{rot}\vec{A}\right)=\vec{J}_{ex}+\vec{J}_{a} \quad (1)$$

Corresponding Author: N. Bennecib, Faculty of Science Engineering, University of Constantine, Constantine, Algeria

where J_{ex} and J_a, μ are the current density in the exciting coil, the current density injected by electrodes, the magnetic permeability and the electric conductivity, respectively. In this study, electromagnetic field is considered to be constant. In the axisymmetric analysis the electric current density has only the φ-component. Using 2D cylindrical r, z coordinates; (1) is developed as:

$$\frac{\partial}{\partial z}\left(\frac{1}{\mu}\frac{\partial(A_\varphi)}{\partial z}\right)+\frac{\partial}{\partial r}\left(\frac{1}{\mu}\frac{1}{r}\frac{\partial(rA_\varphi)}{\partial r}\right)-\frac{\sigma}{r}v\frac{\partial(rA_\varphi)}{\partial z}=-J_{ex}-J_a \tag{2}$$

If we introduce the transformation

$$A = A_\varphi \tag{3}$$

Eq. (2) becomes

$$\frac{\partial}{\partial z}\left(\frac{1}{\mu}\frac{\partial A}{\partial z}\right)+\frac{\partial}{\partial r}\left(\frac{1}{\mu}\frac{1}{r}\frac{\partial A}{\partial r}\right)-\frac{\sigma}{r}v\frac{\partial A}{\partial z}=-J_{ex}-J_a \tag{4}$$

Let Ω be the study domain enclosed by $\Gamma = \Gamma_u \cup \Gamma_q$ with boundary conditions $A=\overline{A}$ on Γ_u, $\frac{1}{r}\frac{\partial A}{\partial n}=\overline{q}$ on Γ_q. $\overline{A}$ and $\overline{q}$ are the prescribed unknown potential and normal magnetic flux, respectively, on the flux boundary Γ_q and n is the unit outward normal direction to the boundary Γ_q.

The motion of the liquid in the magnetic field can be described as (Bahadir and Abbasor, 2005):

$$\mathrm{div}\vec{V}=0 \tag{5}$$

$$\frac{\partial V}{\partial t}+\left(\vec{V}.\vec{\nabla}\right)\vec{V}=-\frac{1}{\rho}\mathrm{gr\vec{a}d}P+\upsilon\Delta\vec{V}+\frac{\vec{F}}{\rho} \tag{6}$$

Where $\vec{V}$ is the velocity vector, P is the density of the liquid, υ is the kinematics viscosity and $\vec{F}$ is Laplace forces which are given by:

$$\vec{F}=\left(\vec{J}_i+\vec{J}_a\right)\wedge\vec{B} \tag{7}$$

where J_i is the induced current density.

The coupled velocity $\vec{V}$ and magnetic induction field $\vec{B}$ is developed.

Next, we will apply a method which uses the vorticity vector $\vec{\xi}(r,z)$ and two vector potentials: hydrodynamic $\vec{\psi}(r,z)$ and magnetic $\vec{A}(r,z)$.

(ψ,ξ,A) **Model:** We introduce two vector potentials $(\vec{A},\vec{\psi})$, the vorticity vector $\vec{\xi}$ and using the following relationships (Krzeminski *et al.*, 1996; Marc, 1999)

$$\vec{B}=\mathrm{r\vec{o}t}\vec{A},\ \vec{V}=\mathrm{r\vec{o}t}\vec{\psi},\ \vec{\xi}=\mathrm{r\vec{o}t}\vec{V} \tag{8}$$

$$v_r=-\frac{1}{r}\frac{\partial\psi}{\partial z},\ v_z=\frac{1}{r}\frac{\partial\psi}{\partial r} \tag{9}$$

$$w=\frac{\partial v_r}{\partial z}-\frac{\partial v_z}{\partial r} \tag{10}$$

where v_r and v_z are the components of the velocity, w is the component of the vorticity.

According to the configuration of the pump proposed, it is about a cylinder with ray 'r' and infinite length along axis (Oz). Under these conditions, the jauge condition is naturally checked. Using the new dependent variables (6) we obtain:

$$\upsilon\left(\frac{\partial^2 w}{\partial r^2}+\frac{\partial^2 w}{\partial z^2}+\frac{1}{r}\frac{\partial w}{\partial r}-\frac{w}{r^2}\right)=\frac{\partial w}{\partial t}+\frac{\partial w}{\partial r}v_r+\frac{\partial w}{\partial z}v_z+\frac{v_r}{r}w+\frac{1}{\rho}\left(\frac{\partial F_z}{\partial r}\right) \tag{11}$$

$$\frac{1}{r}\left(\frac{\partial^2\psi}{\partial z^2}+\frac{\partial^2\psi}{\partial r^2}\right)=-w \tag{12}$$

Poisson equation for pressure: In order to determine the pressure applying the (∇) operator to (6) the pressure is obtained as:

$$\frac{\partial^2 P}{\partial z^2}+\frac{\partial^2 P}{\partial r^2}+\frac{1}{r}\frac{\partial P}{\partial r}=\frac{2\rho}{r^2}\frac{\partial^2\psi}{\partial z^2}.\frac{\partial^2\psi}{\partial r^2}$$
$$\Delta P=\frac{2\rho}{r^2}\frac{\partial^2\psi}{\partial z^2}.\frac{\partial^2\psi}{\partial r^2} \tag{13}$$

NUMERICAL METHODS AND RESULTS

In finite volume method, each node principal "P" is surrounded by four nodes close that to North "N", the south "S", the East "E" and the West "W". By projection of the differential (4) on a basis of projection functions β_i and by integration of this same equation on the volume of control, corresponding to the node "P", we obtain: (Patankar, 1980)

$$a_pA_P=a_eA_E+a_wA_W+a_nA_N+a_sA_S-\\-\left(a'_nA_N-a'_sA_S\right)v_z+d_O \tag{14}$$

Table 1: Parameters for numerical simulation

Parameter	Value
Channel length L	0.14m
Channel radius r	0.03m
Electrode length l	0.08m
Electrical current source density J_{ex}	$-0{,}2.10^7 A\ m^{-2}$
Electrical current density injected by electrodes J_a	$0{,}25.10^7 A\ m^{-2}$

Table 2: Pertinent properties of seawater

	Seawater
Density, ρ(kg m^{-3})	1000
Viscosity, μ(Pa s)	6.10^{-4}
Relative permeability	1
Conductivity, σ(S/m)	50

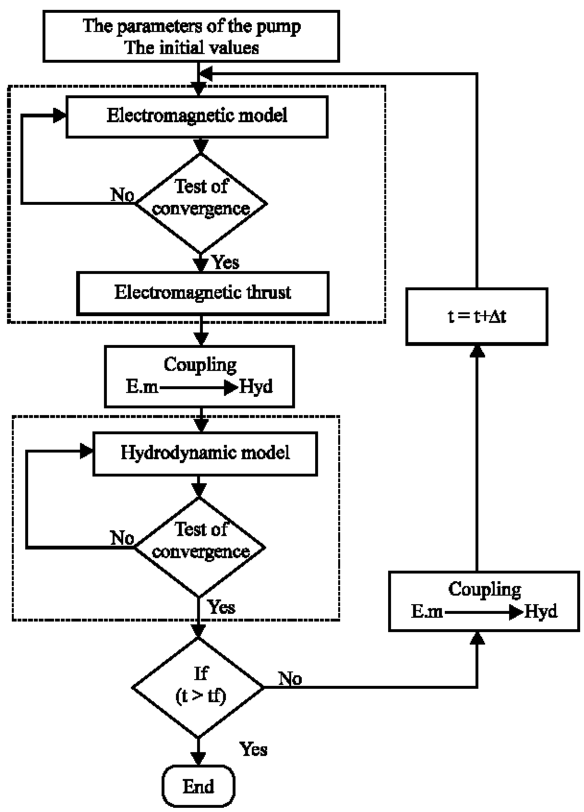

Fig. 2: Computation algorithm

The matrix form of this system of equation is written in the form:

$$[M + vL]\{A\} = \{F\} \qquad (15)$$

where [M+vL] Coefficients matrix, {A} Unknown vector and {F} Source vector.

The resolution of the electromagnetic model is realized by an iterative method (Wait, 1979). After that the hydrodynamic problem will be solved by the same method. The grid remains the same one, once the located nodes, we introduces the source term which allows the coupling between the two equations electromagnetic-flow. The integration of the (11) on the control volume gives:

$$a_p W_P = \sum a_{nc} W_{nc} + a_b \qquad (16)$$

In which a_p terms are the attractive coefficients on W and nc implies summation over the neighbouring nodes of "P" for two dimensional computations and a_b is the source terms.

Finally, the finite volume method is employed for solving the velocity profile across the channel and for study of a two dimensional electromagnetic model in dynamic mode. Parameters for the applied magnetic fields and electric currents plus specific electrode length and its provision have been adjusted for the assessments on the performance of the DC pump MHD.

Table 1 tabulated geometric parameters and applied fields needed for the numerical simulations. In addition the pertinent material properties of seawater are listed in Table 2.

Plots of velocity and pressure profiles are presented for showing the pumping effect. Plots of magnetic potential and thrust forces are also included.

With the Direchlet condition V = 0, $\partial V/\partial z$ and $\partial V/\partial z$ =0 on the line of symmetry like boundary conditions, the descretization equations were solved iteratively by Seidel Gauss method. The computation algorithm of resolution is done in Fig. 2. Owing to the geometric symmetry, only half domain was solved. As a convergence criterion,

$$\|e\| = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(V_i - V_i^{-1}\right)^2} \qquad (17)$$

Where N is the total number of nodes used by the FVM in the studied domain, V_t^{-1} is the past solution of each node and V_i is the present past solution.

The first step is the evaluation of the magnetic field induction by the known magnetic potential vector by Maxwell's equation. After the field B is found, the electromagnetic force can be evaluated at any point at which the current density (J_i+J_a) is specified; this results in new Lorentz forces which are fed back into the Navier-stokes equation and integrated as volumetric momentum sources. The next step is a solution of Navier-stokes. Once the velocity field is updated the Poisson equation is solved. The number of grids used for calculation of the flow field is 60×50 As a result, the calculation of the flow field requires a long computational time because the large magnitude of the electromagnetic force requires a small time-step for a stable solution.

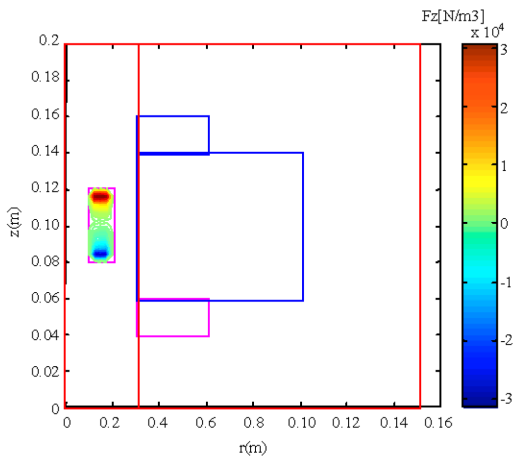

Fig. 3: Distribution of lorentz force F_z for L_1

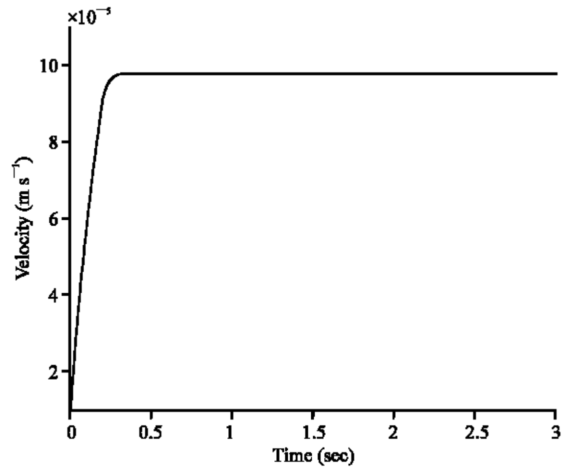

Fig. 6: Instantaneous velocity in the outlet of the channel for L_1

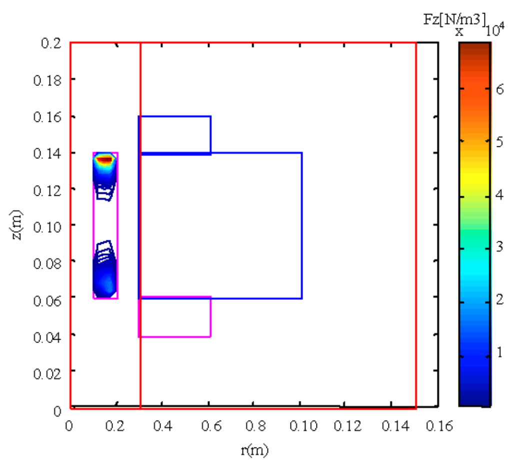

Fig. 4: Distribution of lorentz force F_z for L_2

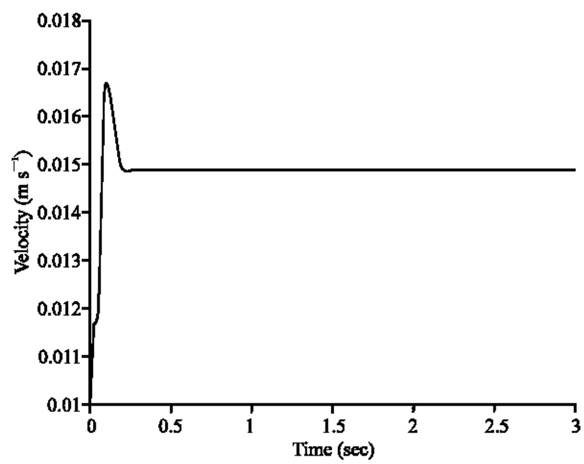

Fig. 7: Instantaneous velocity in the outlet of the channel for L_2

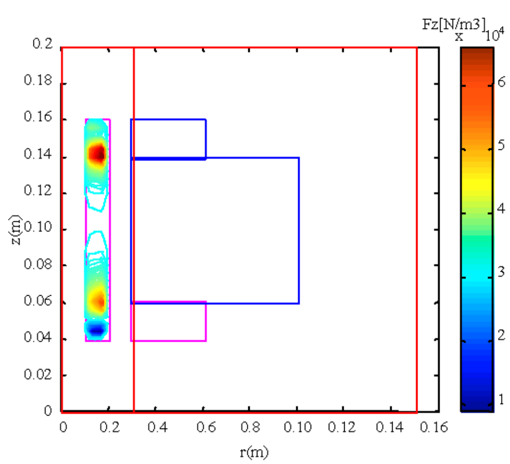

Fig. 5: Distribution of lorentz force F_z for L_3

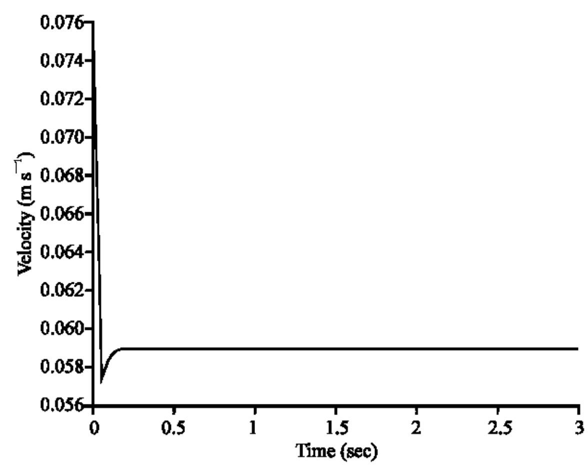

Fig. 8: Instantaneous velocity in the outlet of the channel for L_3

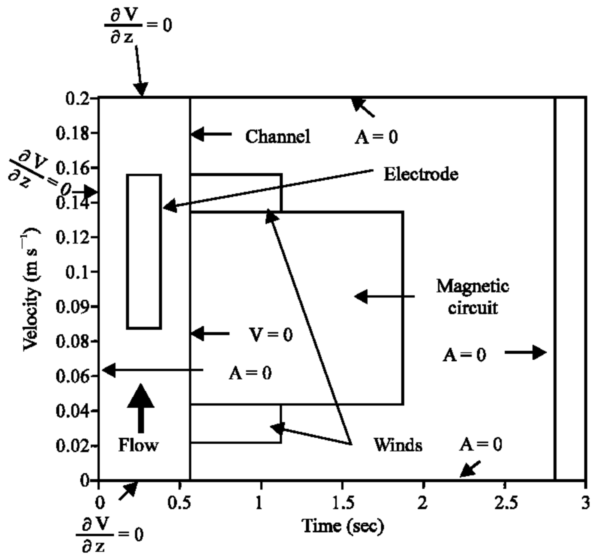

Fig. 9: Schematic of a two-dimensional MHD channel flow configuration

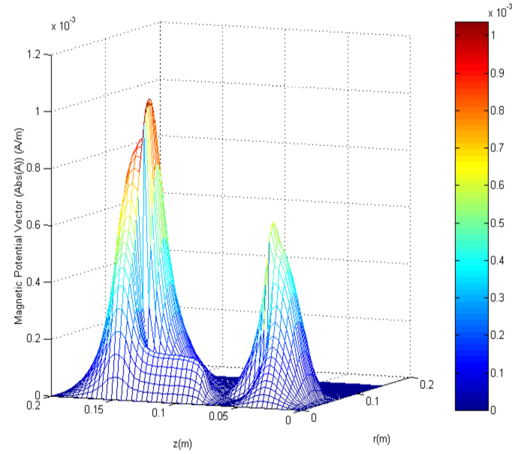

Fig. 10: Magnetic potential vector

The effect of electrode length: The improvement made by this study lies in the optimization electrode length to eliminate the negative forces; the effect of L_{el} on the electrical current density injected J_a and thereafter on the forces calculated by (7), an analysis w as made for three electrode lengths different $L_1 = 0.04$ m, $L_2 = 0.08$ m, $L_3 = 0.12$ m and is shown in Fig. 3-5. These illustrations clearly reveal a negative force for L_1 and L_2 which causes lag on the other hand for L_2 a total absence of a negative force. The maximum value of the force is near the under and bottom electrode and more precisely at the superior wind. These results show the need for optimization this length which is in our case of 0.08m. Therefore, as shown in Fig. 6-8, the flow development is quicker; a transient state then velocity is stabilized.

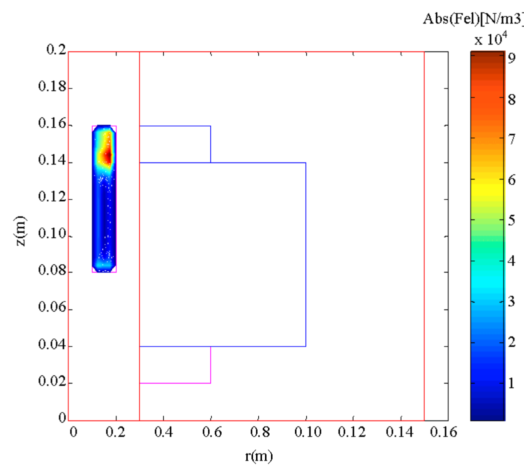

Fig. 11: Axial MHD thrust

Results for DC pump MHD optimized: Simulation calculations were based in this case for our machine optimized; except that we move the electrode towards the higher wind. Only half of the duct is depicted.

Figure 9 and 10 represents a new design of a DC electromagnetic pump optimized and magnetic potential vector. The absolute value of the magnetic potential vector id less significant at the inlet than on the outlet side of the electrode and too weak along the electrode, this is explained by the equi-potential are very concentrated near the outlet of the electrode.

Therefore, as shown in Fig. 11, the axial MHD thrust become much greater increases in the outlet of the electrode leading to push the seawater.

Figure 12 shows velocity of the seawater under the electrode, the similar phenomenon to MHD thrust.

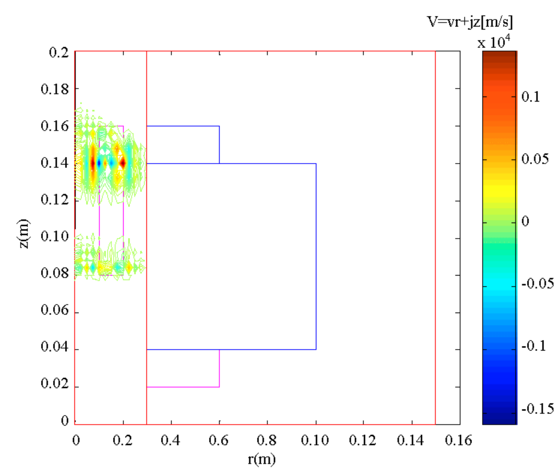

Fig. 12: Axial MHD thrust

The results obtained are in perfect agreement with what was expected on the basis of theoretical considerations and also of results reported by other authors but obtained in different working conditions (Hughes, 1995; Pei-Jen *et al.*, 2004).

CONCLUSION

The present study does two things. In the first place a new design is proposed with an algorithm to represent coupled MHD flows have been employed to investigate the behaviour of a conducting fluid passing through a duct and to understand how the fluid moves in a two dimensional flow determines in large part the latter. The Navier-stokes equations are deterministic.

The second goal is to optimize our machine; the judicious choice of the electrode length removes the effect of lag and increases the force. The originality is then in the electrode number and provision. Considering the simplicity of the configuration suggested and optimized, this study could be the subject of a realization of an MHD engine.

Nomenclature:

$\vec{A}$: Magnetic vector potential [Wb/m],
$\vec{B}$: Magnetic induction [T],
$\vec{D}$: Electric flux density (displacement electric) [A/m^2],
$\vec{E}$: Electric field [V/m],
$\vec{J}$: Electric conduction current density [A/m^2],

$$(\vec{J} = \vec{J}_{ex} + \vec{J}_a + \vec{J}_i)$$

$\vec{J}_i$: Induced current density [A/m^2],
$\vec{J}_{ex}$: Electrical current source density [A/m^2]
$\vec{J}_a$: Electrical current density injected by electrodes [A/m^2]
$\vec{H}$: Magnetic field [A/m],
P : Pressure [Pa],
$\vec{V}$: Flow velocity [m/s],
υ : Kinematic viscosity coefficient [m^2/s],
σ : Electric conductivity [$(\Omega m)^{-1}$],
μ : Permeability magnetic [H/m],
$\vec{\xi}(r,z)$: Vorticity vector,
$\vec{\psi}(r,z)$: Vector potential hydrodynamic,
v_r, v_z : Components of the velocity,
ω : Component of vorticity,
β_i : Projection function,
Ω : Domain in element,
L : Length of electrode [m],
R_{ch} : channel ray[m],

REFERENCES

Bahadir, A.R. and T. Abbasov, 2005. A numerical investigation of the liquid flow velocity over an infinity plate which is taking place in a magnetic field, Int. J. Applied Electromagnetic and Mechanics, pp: 1-10.

Hughes, M., K.A. Pericleous and M. Cross, 1995. The numerical modelling of DC electromagnetic pump and brake flow, Applied Math. Modelling, Vol .19.

John, J.B., 2000. Practical Fluid Mechanics for engineering Application. Eastern Hemisphere distribution.

Krzeminski, S.K., A. Cala and M. Smialek, 1996. Numerical simulation of 2D MHD flows ψ-ξ-A method, IEEE, Trans-magnet, Vol. 32.

Marc, F., 1999. Hydrodynamique physique. Problèmes résolus avec rappels de cours, collection sciences sup. physique, éditeur Dunod.

Patankar, S.V., 1980. Numerical Heat Transfert and Fluid Fluid, series in computational methods in mechanics thermal sciences, Hemisphere publishing corporation.

Pei-Jen, W., C. Chia-Yuan and C. Ming-Lang, 2004. Simulation of two-dimensional fully developed laminar flow for a Magneto-Hydrodynamic (MHD) pump. Biosensors and Bioelectronics 20, Elsevier, pp: 115-121.

Puush, K.K. and M.C. Ira, 2002. Fluid Mechanics, (2nd Edn.), A Harcourt science and Technology Company, Academic Press.

Wait, R., 1979. The numerical solution of algebraic equations, A Wiley-Interscience Publication.

Yukihiro, K., H. Hashizume and S. Toda, 1996. Numerical Analysis of fluid flow with free surface and phase change under electromagnetic force, IEEE. Trans-magnet., Vol. 32.