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Swarm Intelligence Applied To Solve Hydrodynamic And Thermal Problems In Conduction Mhd Pump

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Optimization algorithms are a vital tool in many fields, from machine learning and data science to engineering and finance. They allow us to find the best solution to a given problem by searching through a space of possible solutions and selecting the one that maximizes or minimizes a particular objective function. This article is concerned the optimization procedure based on the particle swarm method uses a fitness function as the minimum of the mass of condaction magnetohydrodynamic pump MHD. The Hydrodynamic and thermel model are carried out by the finite volume method. The optimized results of the performance characteristics of the conduction pump are obtained.

Keywords: Optimization algorithms, PSO, MHD Pump; Maxwell equations thermal equations; Finite volume method; velocity, Electrical power; Temperature.

I. INTRODUCTION

Throughout the centuries, nature has been a source of inspiration, with much still to learn from and discover about. Among many others, Swarm Intelligence (SI), a substantial branch of Artifcial Intelligence, is built on the intelligent collective behavior of social swarms in nature. One of the most popular SI paradigms, the Particle Swarm Optimization algorithm (PSO), is presented in this work,[1]

Particle swarm optimization (PSO) is one such optimization algorithm that has gained popularity due to its simplicity, flexibility, and robustness.

PSO is an iterative optimization technique that was inspired by the behavior of social animals such as birds or fish. It involves a group of particles, or agents, that move through a search space and try to find the optimal solution to a given problem. Each particle is guided by its own experience and the experience of the other particles in the group, and the movement of the particles is determined by a set of rules that are based on the particle's current position, velocity, and the best position it has encountered so far.

PSO, a group of particles is used to represent potential solutions to a problem. Each particle has a position in the search space, which corresponds to a potential solution to the problem. The

particles also have a velocity, which determines how they move within the search space. The basic principle behind PSO is to use the social behavior of the swarm to guide the search for the optimal solution. Each particle in the swarm is influenced by the current position of the other particles, as well as its own personal best position.
The personal best position of a particle is the best solution that it has found so far. The global best position is the best solution found by any particle in the swarm. The particles move towards the global best position, as well as towards their own personal best position, in order to find the optimal solution to the problem.

Magnetohydrodynamics or simply (MHD) is the field of science that studies the movement of conductive fluids subjected to electromagnetic forces. This phenomenon brings together concepts of fluid dynamics and electromagnetism. Formally, MHD is concerned with the mutual interactions between fluid flows and magnetic fields. Electrically conducting and non-magnetic fluids must be used, which limits the applications to liquid metals, hot ionized gases (plasmas) and electrolytes.
Over the years, MHD has been applied to a wide spectrum of technological devices, directed, for example, to electromagnetic propulsion or to biological studies.
Application arises in astronomy and geophysics as well as in connection with numerous engineering problems, such as liquid metal cooling of nuclear reactors, electromagnetic casting of metals, MHD power generation and propulsion [2].

The pumping of liquid metal may use an electromagnetic device, which induces eddy currents in the metal. These induced currents and their associated magnetic fields generate the Lorentz force, and allow the pumping of liquid metal [3,4]. Magnetohydrodynamics is widely applied in various domains, such as metallurgical industry, to transport or the liquid metals in fusion and the marine propulsion [5,6]. The advantage of these pumps, which ensure the energy transformation, is the absence of moving parts.

The interaction of moving conducting fluids with electric and magnetic fields allows for a rich variety of phenomena associated with electro-fluid-mechanical energy conversion [7,8].

The schematic of the MHD pump is shown in (fig.1). The basic principle is to apply an electric current across a channel filled with electrically conducting liquids and a dc magnetic field orthogonal to the currents via permanent magnets.

This article is concerned the optimization procedure based on the particle swarm method uses a fitness function as the minimum of the mass of conduction magneto hydrodynamic pump MHD. The Hydrodynamic and thermel model are carried out by the finite volume method. The optimized results of the performance characteristics of the conduction pump are obtained.

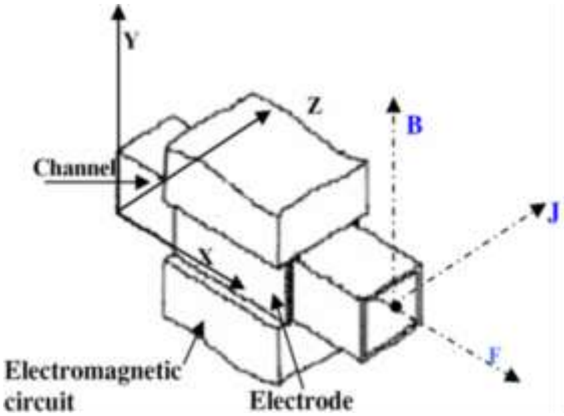

Figure. 1. Scheme of a DC MHD pump [3].

II. MATHEMATICAL ANALYSIS OF PROBLEMS

II.2 LECTROMAGNETIC PROBLEM

The schematic structure of the pump is shown in figure (1). In the pump, the electromagnetic forces are obtained from the Lorentz forces induced by interaction between the applied electrical currents and the magnetic fields, [4,6]. The electromagnetic model of the MHD pump is as follows:

$$\overrightarrow{\mathrm{rot}}\left(\frac{1}{\mu}\overrightarrow{\mathrm{rot}}\vec{A}\right) = \vec{J}_{ex} + \vec{J}_a + \sigma(V.\frac{\partial \vec{A}}{\partial x}) \qquad (1)$$

The magnetic induction and the electromagnetic force are given by:

$$\vec{B} = \overrightarrow{\mathrm{rot}}\vec{A} \qquad (2)$$

$$\vec{F} = \vec{J} \wedge \vec{B} \qquad (3)$$

Following the two-dimensional (2D) developments in Cartesian coordinates, where the current density and the magnetic vector potential are perpendicular to the longitudinal section of the MHD pump, the equation becomes:

$$\frac{-1}{\mu}\left(\frac{\partial^2 A}{\partial x^2}+\frac{\partial^2 A}{\partial y^2}\right)=J_{ex}+J_a+\sigma(V_x\,\frac{\partial A}{\partial x}) \qquad (4)$$

II. 2 THERMAL PROBLEM

The thermal phenomena are studied only in the channel of the MHD pump. So, the governing thermal equation is given by

$$\rho C_p\left(\frac{\partial T}{\partial t}\right) = \mathrm{div}(K\mathrm{grad}(T) + P_s \qquad (5)$$

Where ρ is the density of the fluid, Cp the specific heat, K the thermal conductivity, T the temperature and Ps the thermal source (electric power density) induced by eddy current such as:

$$P_s = \frac{1}{2\sigma} J_i^2 \qquad (6)$$

After developments in Cartesian coordinates, replacing the source term Ps, we obtain:

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial t}\left(K\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(K\frac{\partial T}{\partial y}\right) + \frac{1}{2\sigma} J_i^2 \qquad (7)$$

II.3 Hydrodynamic Problems

The MHD flow of an incompressible, viscous and electrically conducting fluid in a transient state condition is governed by the Navier-Stokes equations [8]:

$$\frac{\partial \vec{V}}{\partial t} + (\nabla.\vec{V})\vec{V} = -\frac{1}{\rho}\nabla p + \nu\Lambda\vec{V} + \frac{\vec{F}}{\rho} \qquad (8)$$

$$\mathrm{div}\vec{V} = 0 \qquad (9)$$

Where **p** the is the pressure of the fluid, **ʋ** the kinemactic viscosity of the fluid, **F** the electromagnetic thrust and **ρ** the fluid density, [12,14].

The development of the equation of the flow in Carte- sian coordinates gives, [11,15]

$$\frac{\partial V_x}{\partial t} + V_x.\frac{\partial V_x}{\partial x} + V_y\frac{\partial V_x}{\partial V_y} = \frac{-1}{\rho}\frac{\partial p}{\partial x} + \nu\left[\frac{\partial^2 V_x}{\partial^2 x^2} + \frac{\partial^2 V_x}{\partial^2 y^2}\right] + \frac{1}{\rho}F_x$$

$$\frac{\partial V_y}{\partial t} + V_x.\frac{\partial V_y}{\partial x} + V_y\frac{\partial V_y}{\partial V_y} = \frac{-1}{\rho}\frac{\partial p}{\partial y} + \nu\left[\frac{\partial^2 V_y}{\partial^2 x^2} + \frac{\partial^2 V_y}{\partial^2 y^2}\right] + \frac{1}{\rho}F_y$$

$$\frac{\partial V_x}{\partial x} + \frac{\partial V_y}{\partial V_y} = 0 \qquad (10)$$

The real difficulty is the calculation of the velocity lies in the unknown pressure. To overcome this difficulty is to relax the incompressibility constraint in an appropriate way. So, the elimination of pressure from the equations leads to a velocity-stream function .

The velocity vector is defined by:

$$\zeta = \overrightarrow{\mathrm{rot}}\ V \qquad (11)$$

The stream function is given in 2D Cartesian coordinates as:

$$\frac{\partial\psi}{\partial y} = V_x\ ; \quad \frac{\partial\psi}{\partial x} = V_y \qquad (12)$$

Where **Vx** and **Vy** the components of the velocity **V**.

We eliminate the pressure from the equation (12) and we use the two new dependent variables ξ and Ψ to obtain the following equation:

$$\frac{\partial\zeta}{\partial t} + V_y\frac{\partial\zeta}{\partial y} + V_x\frac{\partial\zeta}{\partial x} = \nu\left[\frac{\partial^2\zeta}{\partial^2 x^2} + \frac{\partial^2\zeta}{\partial^2 y^2}\right] + \frac{1}{\rho}\left(\frac{\partial F_x}{\partial y} + \frac{\partial F_y}{\partial y}\right) \qquad (13)$$

After substituting equation (11) into equation (12) we obtain an equation involving the new dependent variables **ξ** and **ψ** such as:

$$-\zeta = \frac{\partial^2\psi}{\partial x^2} - \frac{\partial^2\psi}{\partial y^2} \qquad (13)$$

III. NUMERICAL METHOD AND RESULTS

There are several methods for the determination of the electromagnetic fields and the velocity; the choice of the method depends on the type of problem, [11, 12].

In our work, we thus choose the finite volume method; its principle consists on subdividing the field of study (Ω) in a number of elements. Each element contains four nodes of the grid. A finite volume surrounds each node of the grid. [13, 14].

The method consists of discretising differential equations by integration on finite volumes surrounding the nodes of the grid. In this method, each principal node P is surrounded by four nodes N, S, E and W located respectively at North, South, Est and West (Figure.2) We integrate the electromagnetic thermal and hydrodynamic equations in the finite volume method delimited by the surfaces E, W, N and S, [15]. Finally we obtain the algebraic equation which is written as:

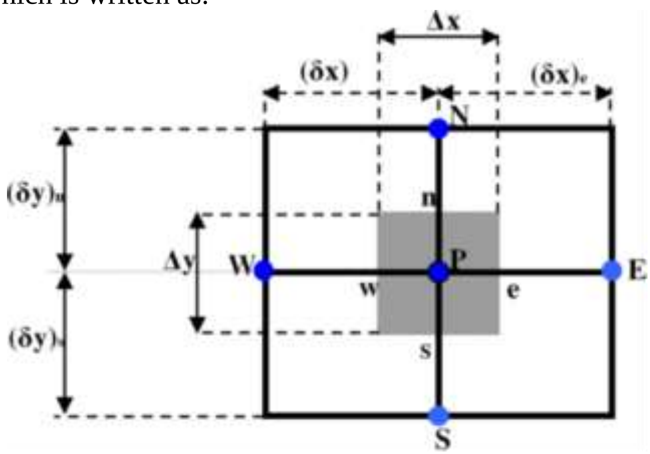

Figure 2. Discretisation in finite volume method.

$$\int_w^e \int_s^n \left[\frac{1}{\mu} \left(\frac{\partial^2 A}{\partial x^2} + \frac{\partial^2 A}{\partial y^2} \right) \right] dx\,dy = \int_w^e \int_s^n (J_{ex} + J_a + \sigma V_x \frac{\partial A}{\partial x}) dx\,dy \tag{14}$$

$$\rho C_p \int_t \int_s^n \int_w^e \frac{\partial T}{\partial t} dxdydt = \int_t \int_s^n \int_w^e \frac{\partial}{\partial x}\left(K \frac{\partial T}{\partial x} \right) dxdydt + \int_t \int_s^n \int_w^e \frac{\partial}{\partial y}\left(K \frac{\partial T}{\partial y} \right) dxdydt$$
$$+ \int_t \int_s^n \int_w^e P_S dxdydt$$

After integration, the final algebraic equation will be:

$$a_p A_p = a_e A_e + a_w A_w + a_n A_n + a_s A_s + d_p \tag{15}$$

$$a_E = \frac{\Delta y}{\mu_e (\delta x)_e}, \; a_W = \frac{\Delta y}{\mu_w (\delta x)_w}, \; a_N = \frac{\Delta x}{\mu_n (\delta y)_n}, \; a_S = \frac{\Delta x}{\mu_s (\delta y)_s},$$

$$c_P T_P = c_E T_E + c_w T_W + c_N T_N + c_S T_S + d_P \tag{16}$$

$$c_E = \frac{K\Delta t\Delta y}{(\delta x)_e},\ c_W = \frac{K\Delta y\Delta t}{(\delta x)_w},\ c_N = \frac{K\Delta t\Delta x}{(\delta y)_n},\ c_S = \frac{K\Delta t\Delta x}{(\delta y)_s},$$

We use the same steps for the hydrodynamic problem:

$$\int_{tf}^{t}\int_{s}^{n}\int_{w}^{e}\left(\frac{\partial\zeta}{\partial t}+Vy.\frac{\partial\zeta}{\partial y}+Vx.\frac{\partial\zeta}{\partial x}\right)dxdydt=\int_{tf}^{t}\int_{s}^{n}\int_{w}^{e}\left(\nu\left[\frac{\partial^2\zeta}{\partial^2 x^2}+\frac{\partial^2\zeta}{\partial^2 y^2}\right]\right)dxdydt$$
$$+\int_{tf}^{t}\int_{s}^{n}\int_{w}^{e}\left(\frac{1}{\rho}\left(\frac{\partial Fx}{\partial y}+\frac{\partial Fy}{\partial y}\right)\right)dxdydt \qquad (17)$$

$$\int_{s}^{n}\int_{w}^{e}\left(\frac{\partial^2\psi}{\partial x^2}-\frac{\partial^2\psi}{\partial y^2}\right)dxdy=-\int_{s}^{n}\left(\int_{w}^{e}\zeta dxdy\right. \qquad (18)$$

$$b_P\zeta_P = a_e\zeta_e + b_w\zeta_w + b_n\zeta_n + b_s\zeta_s + b_0\zeta_0 + d_P \qquad (19)$$

The resolution of the electromagnetic, thermic and the hydrodynamic equations makes it possible to determine the magnetic potential vector, magnetic induction ($\vec{A}, \vec{B}$)the Electromagnetic force F, temperature and the velocity in the channel of the conduction pump.

IV. BASIC PARTICLE SWARM OPTIMIZATION ALGORITHM

In the partial PSO, the speed and position of each particle change according the following equation

$$V_i^k = \omega.V_i^k + c_1r_1(Pbesti - x_i^k) + c_2r_2(Gbest - x_i^k) \qquad (19)$$
$$x_i^{k+1} = x_i^k + V_i^k \qquad (20)$$

where V represents the velocity vector, ω is the inertia weight utilized to balance the local exploitation and global exploration, i denotes particle's index, t is the current iteration's number, x is the position vector (or a potential solution), r1 and r2 are random vectors uniformly distributed within the range [0, 1] and c1 and c2, called "acceleration coefcients", are positive constants. To get the optimum solution, each particle moves towards its prior personal best position (Pbest) and the global best position (Gbest) in the swarm.
The flow chart represented by Fig. 3 groups together the steps of the PSO.

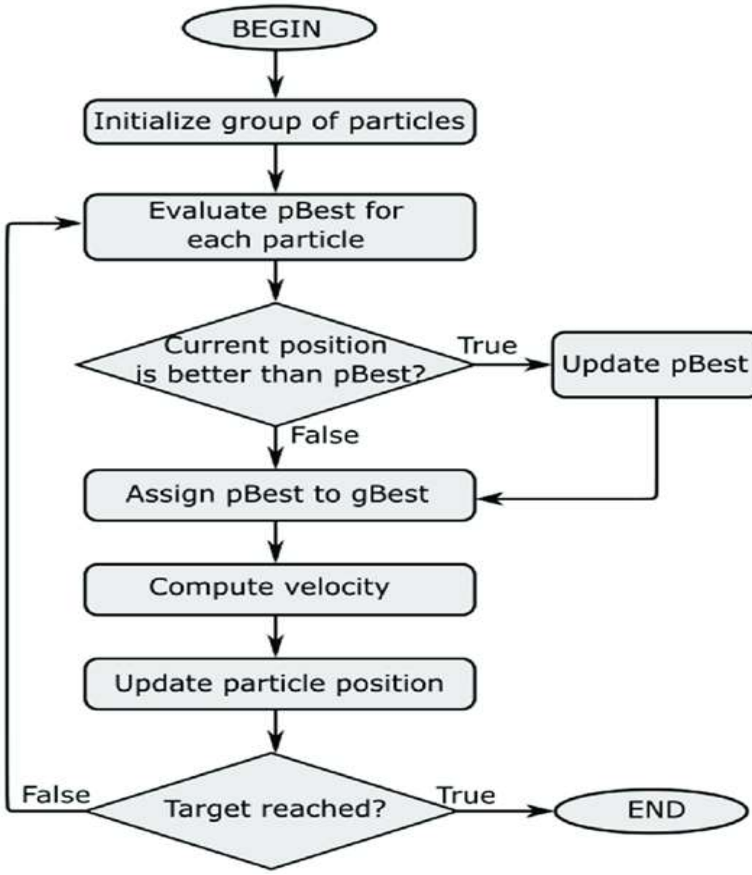

Figure. 3. PSO Flow chart

The optimization problem is to determine the minimum of the mass of the pump as follows:
Min mass (X) subjected to
X lower ≤ X ≤X upper
where:
X1 : channel's length;
X2 : channel's width ;
X3 : inductor's length;
X4 : inductor's width;
X5 : coil's length;
X6 : coil's width;
X7 : electrode's length;
X8 : electrode's width.

PSO parameters used in our optimization of a conduction MHD pump are given in Table1 :

Parameters	Value

C1	1
C2	0.1
inertia weight	0.2
Size of the swarm	20
bird_ setp	20
Dimension of the problem	8

V. RESULTS AND DISCUSSION

The obtained results after the optimization are given in table 2.

Parameters	before optimization	After optimization
X1 [m]	0.2	0.1952
X2 [m]	0.2	0.1952
X3 [m]	0.07	0.0601
X4 [m]	0.3	0.2804
X5 [m]	0.025	0.0211
X6 [m]	0.15	0.1106
X7 [m]	0.05	0.0503
X8 [m]	0.1	0.0804
Iron mass (Kg)	4.1212	3.3070
Coil’s masse (Kg)	1.6725	0.51937
Electrode’s masse (Kg)	0.0520	0.0262
Mercury’s masse (Kg)	3.2496	3.1568
Pump’s masse (Kg)	9.1474	7.55

The figures (5) and (6) represent respectively the equipotential lines and the distribution of the magnetic vector potential in the MHD pump.

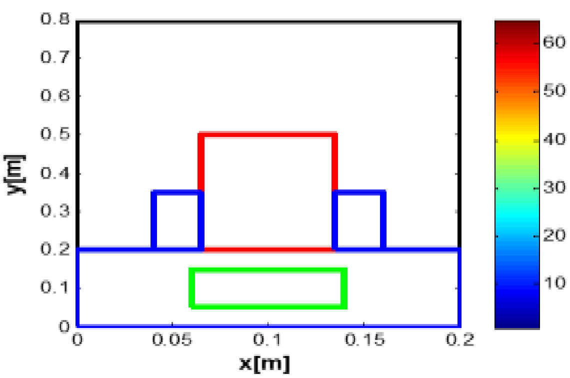

Figure 4. A conduction MHD pump configuration

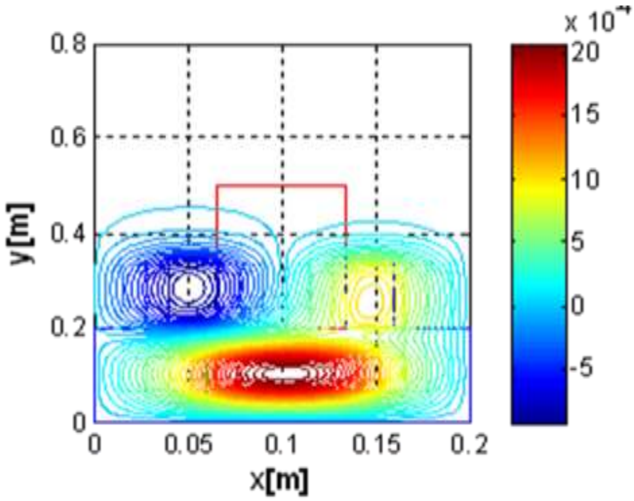

Figure. 5 – Equipotential lines in a DC MHD pump

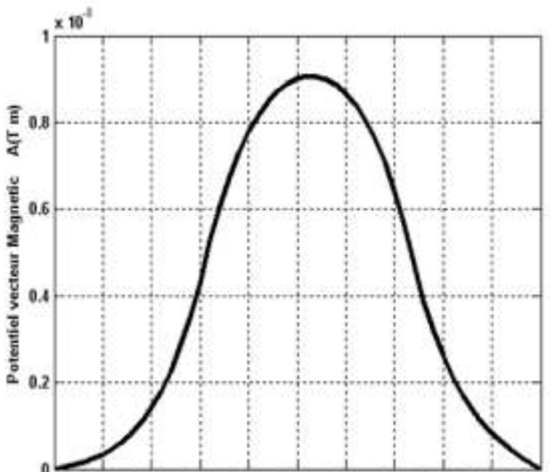

Figure. 6 – Magnetic vector potential in a Dc MHD pump

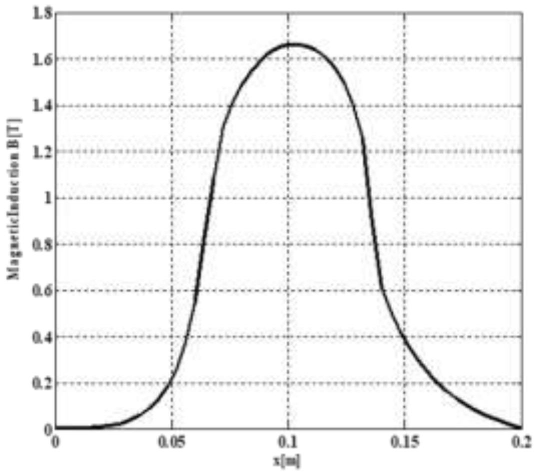

Figure. 7 – Magnetic induction in the MHD pump

The figure (7) represents the magnetic induction in the channel. It is shown that, the magnetic induction reaches its maximum value at the inductor and in the medium of the channel.

This figure (8) represents the electromagnetic force in the channel; it is note that, the maximum value in the medium of the channel of the MHD pump.

The figure (9) represents the velocity in the channel of the MHD pump. It is noticed that the velocity of the fluid flow passes by a transitory mode then is stabilized like all electric machine and the steady state is obtained approximately after ten seconds. The results obtained are almost identical qualitatively to those obtained by [6, 14].

The figure (10) shows the electric power density in the channel. The maximum induced power reaches $2.157*10^6 W / m^3$. The pace obtained is directly related to that of the eddy current density. This characteristic of the heat source is used in the numerical calculation of the temperature.

The figure (11) shows the distribution of the temperature in the channel of the MHD pump. It is noticed that the temperature passes by a transitory mode then is stabilized.

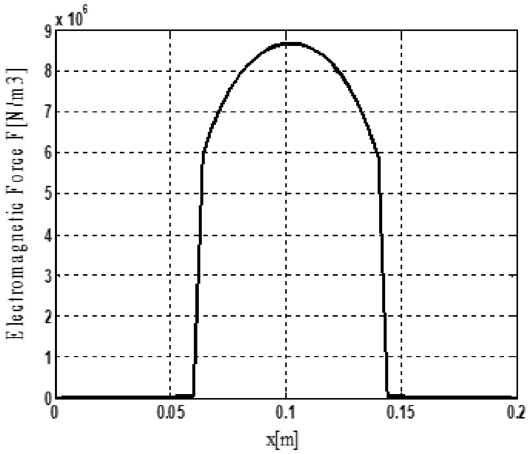

Figure. 8 – Electromagnetic force in The MHD pump

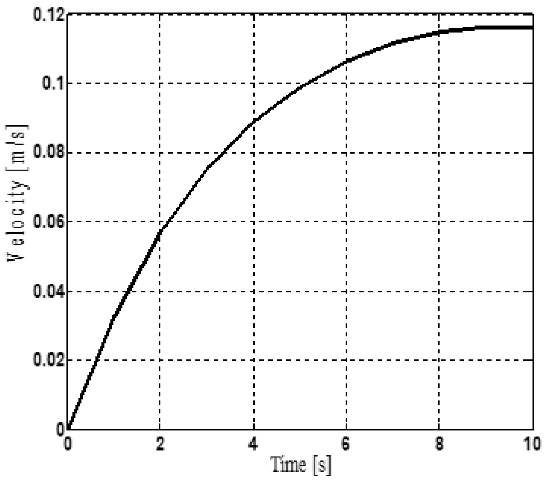

Figure. 9 –Velocity in the channel of the MHD pump

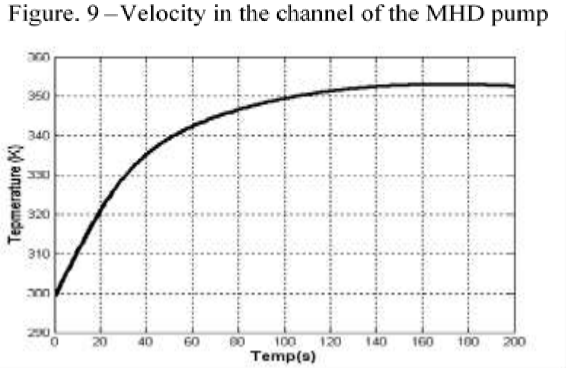

Figure. 11 – The temperature in the channel of the MHD pump

5. CONCLUSION

This paper is aimed at the conception by optimization of the magnetohydrodynamic pump. The optimization design procedure is applied successfully by PSO method.

PSO is a powerful algorithm approach that has been applied with great success. It has a limited number of parameters to adjust.

Various characteristics such as the distribution of the magnetic vector potential, the magnetic flux density, the electromagnetic force, the velocity and temperature in the channel are given. The results of velocity obtained are almost identical qualitatively to those obtained by Majid Ghassemi and P.J. Wang.

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