The Heat Transfer Analysis of The Hyperbaric Oxygen Chamber with Cooling System

S. Y. Lin, David T. W. Lin, C. C. Chang, and C. N. Huang, *Member*, *IEEE*

***Abstract*—The overheated problem is the important issue in the operation of the hyperbaric oxygen chamber. A cooling system is applied to reduce the temperature of the hyperbaric oxygen chamber. We present the finite element method to build three types cooling system for solving the overheated phenomena in this problem. For achieving the better cooling way, this investigation considers different types of cooling channel and pressure of the chamber in this simulated process. These simulated results show that the proposed method is accurate, stable, and efficient for handling the heat transfer problems. We expect that the proposed study can apply to ameliorate the overheated problem effectively.**

***Index Terms*—Hyperbaric Oxygen Chamber, Overheat problem, Cooling System**

I. INTRODUCTION

MOST countries in the world, air conditioners are used to solve the internal heat generation problem of the hyperbaric oxygen chamber. However, the oxygen concentration will be reduced by using air conditioners. The purpose of our study is to design the external cooling system and reduce the temperature of the oxygen chamber.

A cooling system has been used to improve the performance of the hyperbaric oxygen chamber in several previous researches. Chen et al. [1] illustrate that the energy efficiency in the hyperbaric oxygen chamber with water-cooled conditioner is better than the same one using air conditioner. Castro et al. [2] show that the forced water withdrawal is an optimal operation to relieve the cooling tower load as the additional heat removes from the cooling tower. In addition, Heikkila and Milosavljevic [3] study the connection of an industrial cooling tower installation. Another studies of Tan and Deng [4] also include the developing an analytical method for evaluating the heat and mass transfer characteristics in a reversibly used water-cooling tower (RUWCT), and other operational aspects of cooling tower.

Voicu et al. [5] conduct the numerical study of steady state, simultaneously developing, laminar mixed convection in a vertical double pipe heat exchanger for upward parallel flow. The elliptic model is considered in this study. Ho and Rahman [6] present their study on fluid flow and heat transfer of liquid hydrogen in a zero boil-off cryogenic storage tank in a microgravity environment. The study focuses on a 3D finite element model and employs a set of numerical simulations to solve the velocity and temperature fields of liquid hydrogen in steady state condition. In this study a complex structures of 3D velocity, and temperature distributions are presented.

Wang et al. [7] present the forced convection heat transfer characteristics in a vertically upward internally ribbed tube at supercritical pressures investigated by the experiment. Duffey and Pioro [8] use an existing operating supercritical water (SCW) experience and turbines in the coal-fired power plants. This research also include the investigating on heat transfer and pressure drop at supercritical conditions which using carbon dioxide as a modeling fluid as a cheaper and faster alternative to using SCW. The objectives are to assess the work that is done with the supercritical carbon dioxide and to understand the specifics of heat transfer at the supercritical conditions. Bhowmik and Tou [9] perform the experiment on the transient forced convection heat transfer from a four-in-line chip module. Kdtf [10] presents a computational study of the flow and convective heat transfer in the cylindrical reversed flow combustion chambers, and the elliptic solver is used to incorporate the k-ε turbulence model in the study. The results show that heat transfer in the reversed flow combustion chamber could be improved by proper geometry for the required output. Bhowmik et al. [11] perform a study of general convective heat transfer from an in-line four simulated electronic chips in a vertical rectangular channel using water as the working fluid. The effects of heat fluxes, flow rates and geometrical parameters such as chip number are investigated. Empirical correlations are developed for relations using Nusselt number, Reynolds number and Grashof number, based on channel hydraulic diameter. Panjeshahi et al. [12] study the Advanced Pinch Design (APD) which combined pinch technology. The mathematical programming is developed for minimum cost achievement, and introducing ozone treatment technology for considered cycle water quality. The authors use an improved method about APD methodology called Enhanced Cooling Water System Design (ECWSD) as the APD supplementary methodology to provide water and energy

Manuscript received December 8, 2010; revised December 8, 2010.

S. Y. Lin is currently an graduate student of the Institute of Mechatronic System Engineering, National University of Tainan, Tainan 701, Taiwan, R.O.C. (phone: +886-921-208-325; e-mail: lin08288@yahoo.com.tw).

David T. W. Lin is currently an associate professor at Graduate Institute of Mechatronic System Engineering, National University of Tainan, Tainan 701, Taiwan, R.O.C. His main research interests are optimization, thermal-fluid of mechatronic system, and inverse problem. (e-mail: david@mail.nutn.edu.tw).

C. C. Chang is currently a professor at Graduate Institute of Mechatronic System Engineering, National University of Tainan, Tainan 701, Taiwan, R.O.C. His main research interests are System Engineering, Application of CAD/CAM/CAE, Reverse Engineering, Rapid Prototyping and Rapid Tooling in Industrial and Medical Application, Micro-Manufacturing. (e-mail: jeff0718@mail.nutn.edu.tw).

C. N. Huang is an associate professor at Graduate Institute of Mechatronic System Engineering, National University of Tainan, Tainan 701, Taiwan, R.O.C. His main research interests are mechatronic system, hybrid-power control, and vehicular electronics. (e-mail: kosono@mail.nutn.edu.tw).

conservation, and also minimum cost and environmental impacts.

Our study emphasizes on the application of cooling water system and discusses the temperature distributions of the high pressure oxygen chamber. We also use the heat transfer model to solve the thermal problem of the oxygen chamber.

II. MODELING AND NUMERICAL ANALYSIS

The simulated model is considered in this study for examining the performance of the optimization approach. Figure.1 presents a schematic illustration of the problem considered in the present analysis. As shown, the cavity combined with the cooling water on the bottom surface is modeled as the water-cooled system.

The heat removal includes convection, conduction; the effects of radiation are neglected. The cavity is denoted as a domain, V, initially the temperature is kept at a constant temperature, T_{inf}. Assume that the oxygen in the cavity is the non-isothermal flow. The governing equations are listed here:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0 \tag{1a}$$

$$\rho \frac{\partial \vec{v}}{\partial t} + \rho \nabla \cdot (\vec{v} \times \vec{v}) = -\nabla p + \mu \nabla^2 \vec{v} - \rho g \beta (T - T_0) \tag{1b}$$

$$\rho C_p \frac{\partial T}{\partial t} + \nabla \cdot (-k \nabla T) = -\rho C_p u \cdot \nabla T + Q \tag{1c}$$

Where: C_p denotes as the heat capacity $(J/kg \cdot K)$, k is the thermal conductivity $(W/m \cdot K)$, and Q refers to the heat source (W/m^3).

A commercial COMSOL code is employed to analysis the heat transfer phenomena of this system. Figure. 1 shows the 3D mesh model of the hyperbaric oxygen chamber. The cooling water is designed under the iron plate to decrease the high temperature in the chamber. The material of chamber is assumed to be made of iron.

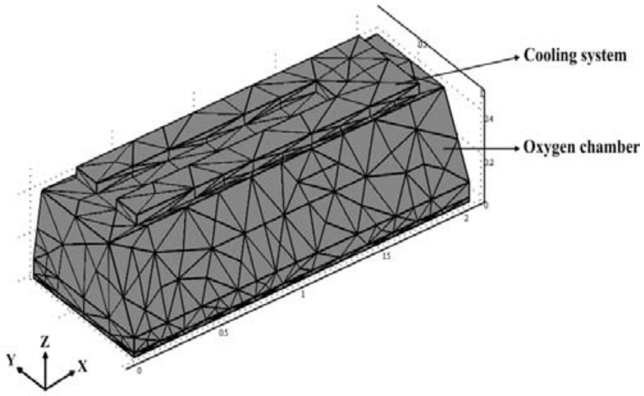

Fig. 1. The mesh model of the hyperbaric oxygen chamber cooling system.

We define the boundary conditions of our proposed model based on the interface between the chamber and the cooling channel is assumed continuity and the different types of the boundary. Additionally, The temperature of the cooling is set as the inlet channel is T_i = 283.15K, the temperature of the bottom of iron plate T_p =301.15K and the oxygen inlet temperature is T_o =301.15K, and the velocity of cooling flow is 1m/s, the pressure in the chamber is 1.5 atm. Besides, the outside boundary conditions of chamber in the model are assumed as heat flux.

Furthermore, the fluid–thermal interaction flow is selected for the simulation of the 3D model. The outside walls of a conduit are considered to be adiabatic condition. In addition, the cooling system design also affects the temperature variation rate of the oxygen chamber. There are three kinds of the cooling system type, the U shape type, the rectangle type, and the multi-U shape type are simulated in this study.

III. RESULTS AND DISCUSSION

Fig. 2 demonstrates the temperature contour of the chamber without a cooling system. It shows that if we do not set up any cooling channel in the chamber, the temperature will be upward uniformly and higher than environmental temperature at 1.5 atm.

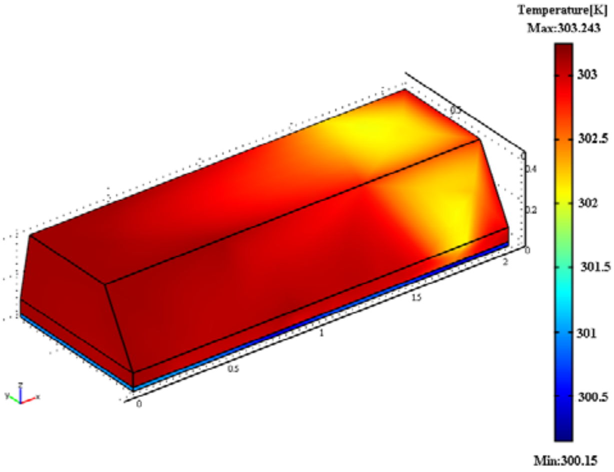

Fig. 2. The temperature contour of the chamber without cooling flow.

Fig. 3 shows the simulated temperature contour of the chamber. It illustrates that the temperature inside the chamber will be decreased with the U shape cooling system. Through the comparison between Fig. 2 and Fig. 3, we observe that the temperature with cooling system is lower than the one without cooling system apparently.

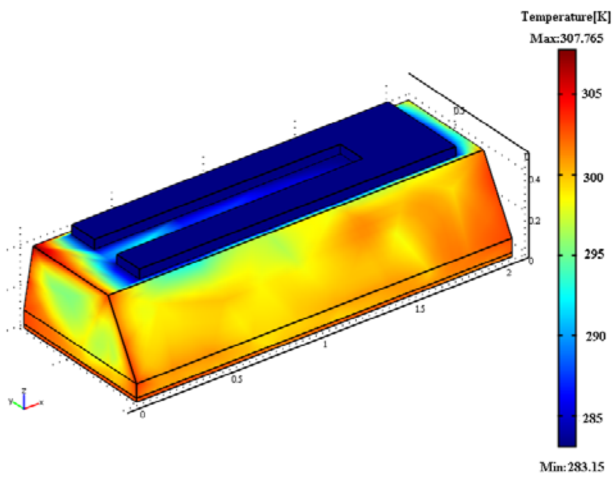

Fig. 3. The temperature contour of the chamber with U shape cooling system.

The temperature contour of the chamber with the cooling system is shown in Fig. 4. We design the rectangle type to find the results in the different kinds of cooling system and obtain the temperature profiles obviously through out the chamber. The detailed results are show in Fig. 6.

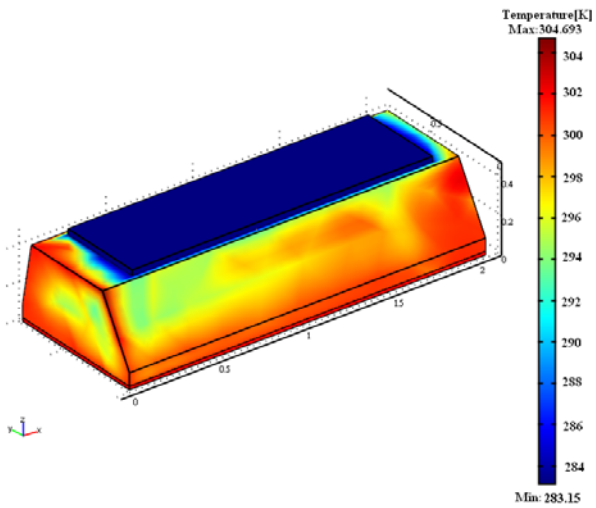

Fig. 4. The temperature distribution of the chamber with cooling channel.

The simulated result of the temperature distribution with the multi-U shape cooling channel is shown in Fig. 5. Accordingly, we recognize that the temperature significantly reduced when we set the cooling system on the chamber through Fig. 2 to Fig. 5.

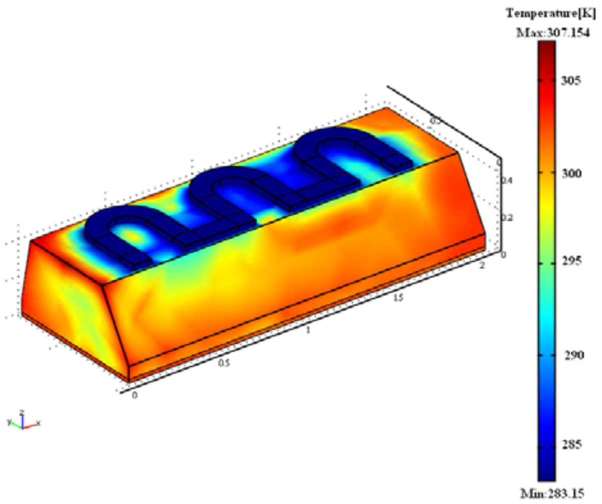

Fig. 5. The temperature distribution of the chamber with cooling channel.

From Fig. 3 to Fig. 5, we design three kinds of cooling model and find out which is the best one. Accordingly, we easily recognize that the system with cooling system channel is better than the one without cooling system.

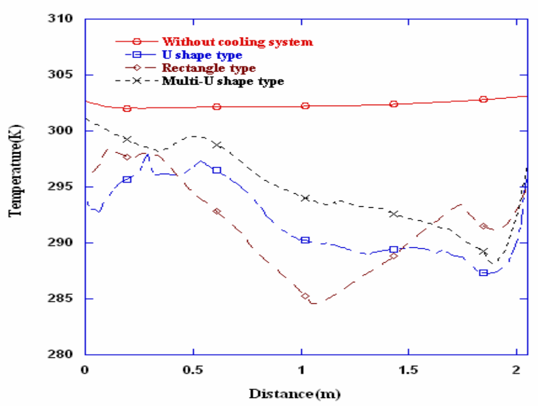

Fig. 6. The temperature distribution of the channel with and without cooling channel.

Fig. 6 shows that the temperature profiles inside the chamber with different types of the cooling system and compares with the one without the cooling system. We recognize that the chamber with cooling channel is more effective than the one without the cooling channel. Thus, a cooling system can be used for solving the overheated problems in the chamber. We recognize that the U type channel is appropriate than other cooling channel, the temperature profile is lower than the other kinds of shape cooling system from 0 m to 0.5 m and 1.5 m to the end of the chamber. In the part from 0.5 m to 1.5 m of the chamber, the temperature profile with rectangle cooling channel decreases from 294.52 K to 290.09 K. It is better than the other kinds of design.

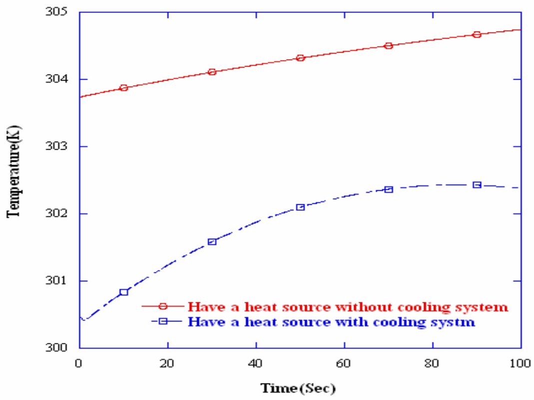

Fig. 7. The temperature distribution with and without cooling system have the heat source in the chamber.

In Fig. 7, we assume a heat source inside the chamber and compare the temperature profile in the transient case with and without cooling system. We observe that the temperature is up to 304.74 K without cooling system is higher than the one with cooling system (302.38 K) at 100 sec and 1.5 atm.

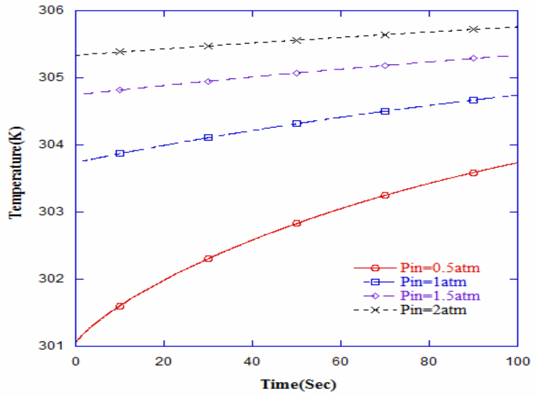

Fig. 8. The temperature distribution without cooling channel has a heat source in four kinds of pressure in inlet of the chamber.

Through out the Fig. 8, there are four kinds of pressure in the chamber. The temperature increases from 303.74 K to 305.76 K as the pressure from 0.5 atm up to 2 atm at 100 sec in the chamber. We can observe that the temporal temperature profile at pressure at 0.5 atm (up from 301.05 K to 303.74 K) is lower than the one at pressure at 2 atm (up from 305.34 K to 305.76 K) evidently.

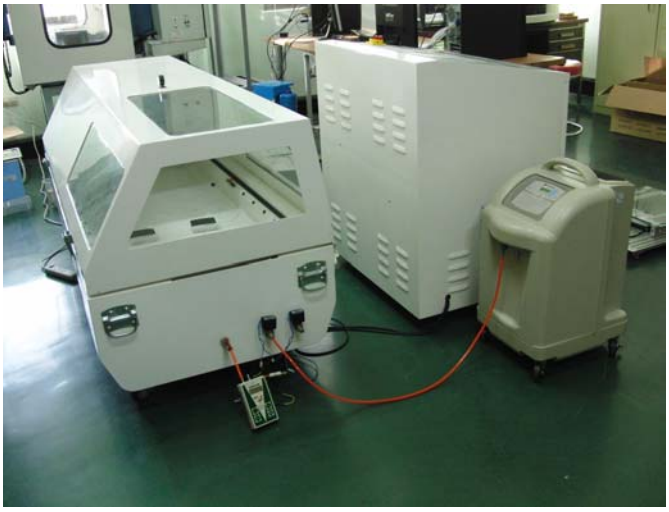

Fig. 9. The diagram of the experimental apparatus.

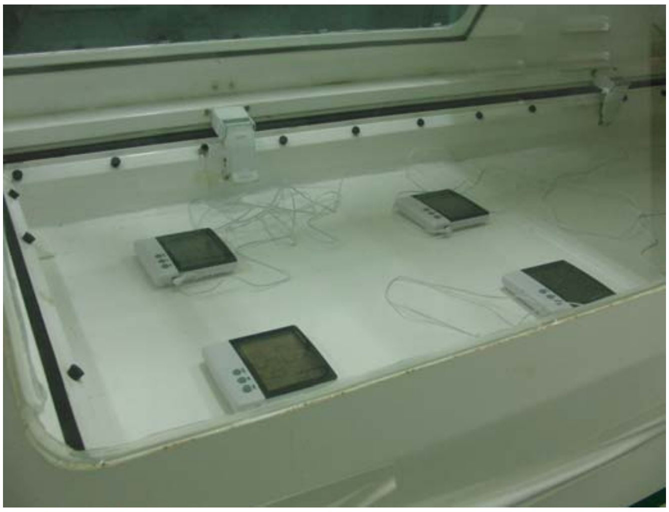

Fig. 10. The diagram of the temperature testing.

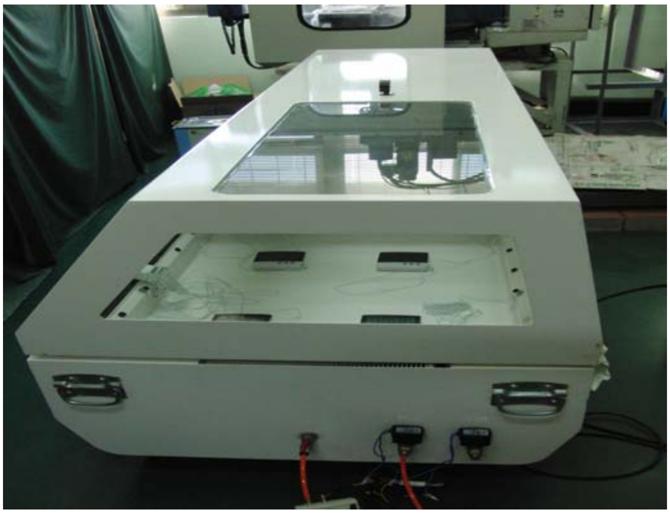

Fig. 11. The diagram of the hyperbaric oxygen chamber.

We have been built the experimental apparatus for the validation as Figs. 9-11.

In future, we will process the experiment in order to compare the temperature profiles of the oxygen chamber with optimal process. In the experiment, thermographs will be used to measure the temperature in the chamber as Fig. 10 and Fig. 11.

IV. CONCLUSIONS

Exploring the temperature distribution inside the high-pressure oxygen chamber at various types of the cooling flow system and understanding how our proposed cooling system has an effect on the high-pressure chamber is presented. The temperature variation of hyperbaric oxygen chamber is simulated by the finite element method.

The simulation demonstrates that without a cooling system in the high pressure oxygen chamber, the temperature in the chamber is higher than with a cooling system on the chamber.

From different kinds shape of cooling system, we can observe that the temperature distribution of the chamber with the cooling system including U shape, rectangle shape, and multi-U shape type is lower than the one without the cooling system at 1.5 atm. The performance of the cooling system with U shape is better than other types, it observes clearly at the position of 0 m to 0.5 m and 1.5 m to 2.05 m in the chamber. In the pressure increasing process, the temperature will be increased. The simulated results prove that the design of the cooling system and the operating pressure will affect the temperature distribution of the oxygen chamber. In the future, the genetic algorithm will be used to process the optimal design of this study.

REFERENCES

[1] H. Chen, W. L. Lee, and F. W. H. Yik, "Applying water cooled air conditioners in residential buildings in Hong Kong," *Energy Conversion & Management*, vol. 49, no. 6, pp. 1416–1423, 2008.

[2] M. M. Castro, T. W. Song, and J. M. Pinto, "Minimization of operational cost in cooling water system," *Institution of Chemical Engineers*, vol. 78, pp. 4-7, 2000.

[3] P. Heikkila, and N. Milosavljevic, "A comprehensive approach to cooling tower design," *Applied Thermal Engineering*, vol. 21, no. 9, pp. 899–915, 2001.

[4] K. Tan and S. Deng , "A numerical analysis of heat and mass transfer inside a reversibly used water cooling tower," *Build Environ*, vol. 38, pp. 91-97, 2003.

[5] I. Voicu, T. Maré, N. Galanis, J. Miriel, and I. Colda. , "Mixed convection in a vertical double pipe heat exchanger," *International Journal of Thermal Sciences* 46, pp. 540–550, 2007.

[6] S. H. Ho and M. M. Rahman, "Three-dimensional analysis for liquid hydrogen in a cryogenic storage tank with heat pipe–pump system," *Cryogenics* 48, pp. 31–41, 2008.

[7] J. Wang, H. L. Guo, S. Yu, Y. Zhang, and T. Chen., "Investigation of forced convection heat transfer of supercritical pressure water in a vertically upward internally ribbed tube," *Nuclear Engineering and Design*, pp. 1956–1964, 2009.

[8] R. B. Duffey and I. L. Pioro, "Experimental heat transfer in supercritical water flowing inside channels (survey)," *Nuclear Engineering and Design* 235, pp. 913-924, 2005.

[9] H. Bhowmik and K. W. Tou, "Study of transient forced convection heat transfer from discrete heat sources in a FC-72 cooled vertical channel," *International Journal of Thermal Sciences* 44, pp. 499–505, 2005.

[10] M. Kdtf, "Flow and convective heat transfer in cylindrical reversed flow combustion chambers," *Int. Comm. Heat Mass Transfer*, vol. 23, no. 8, pp. 1151 – 1161, 1996.

[11] H. Bhowmik, C. P. Yso, K. W. Tou, and F. L. Tan, "Convection heat transfer from discrete heat sources in a liquid cooled rectangular channel," *Applied Thermal Engineering* 25, pp. 2532-2542, 2005.

[12] M. H. Panjeshahi, A. Ataei, M. Gharaie, and R. Parand, "Optimum design of cooling water system for energy and water conservation," *Chemical Engineering Research and Design 87*, pp. 200-209, 2009.

[13] D. A. Coley, An Introduction to Genetic Algorithms for Scientists and Engineers, World Scientific, USA, 1998.

[14] Y. J. Cao, and Q. H. Wu, "Teaching genetic algorithm using matlab," *Intl. J. Elect. Enging. Educ.*, vol. 36, pp. 139-153, 1999.