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Flow Characteristics of An Atmospheric Pressure Plasma Torch

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Abstract

The atmospheric pressure plasma is regarded as an effective method for surface treatments because it can reduce the period of process and doesn't need expensive vacuum apparatus. The performance of non-transferred plasma torches is significantly depended on jet flow characteristics out of the nozzle. In order to produce the high performance of a torch, the maximum discharge velocity near an annular gap in the torch should be maintained. Also, the compulsory swirl is being produced to gain the shape that can concentrate the plasma at the center of gas flow. In this work, the distribution of gas flow that goes out to atmosphere through a plenum chamber and nozzle is analyzed to evaluate the performance of atmospheric pressure plasma torch which can present the optimum design of the torch. Numerical analysis is carried out with various angles of an inlet flow velocity. Especially, three-dimensional model of the torch is investigated to estimate swirl effect. We also investigate the stabilization of plasma distribution. For analyzing the swirl in the plenum chamber and the flow distribution, FVM (finite volume method) and SIMPLE algorithm are used for solving the governing equations. The standard k-model is used for simulating the turbulence.

Keywords : Non-transferred plasma torch, Cold plasma, Swirl effect, Plasma distribution

1. INTRODUCTION

The shape of torch is utilized to generate cold plasma, which is used in surface treatment of metal. We can get high reaction temperature, using the cold plasma other than using the heat source by conventional method. Moreover, due to the simple method of technology many development researches have been processed recently[1, 2].

The high temperature and thermal energy that are occurred from the plasma generator are not only used in reinforcing the working efficiency but also used in more efficient and higher technology. In addition, we can expect the plasma is easier in heating, accurate in controlling the temperature and precise in adjusting the direction of heat flow.

The most of existing method of using plasma torch generates the plasma only in vacuum state. And due to the higher expense of vacuum apparatus and generator, the existing method is lack of economical efficiency and productivity. For resolving those problems, we have studied flow characteristics to develop the atmospheric pressure plasma torch.

For stabilizing the plasma that is generated in

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using atmospheric plasma torch, the flow behavior is generally to plasma torch[3]. Also by concentrating the generated plasma in the center of jet flow, the uniformity may be obtained to the surface treatment. There are two kinds of method to get these effects. Firstly, there is the wall-stabilization in which the plasma is concentrated to the center by using decrease of electrical conductivity through cooling the outer wall while surrounding the arc occurred space with cold metal wall, which is for the stabilization of a flame and decreasing of heat loss. Secondly, there is the vortex-stabilization in which the plasma is surrounded by swirl that is occurred by injecting the plasma gas as incline.

For the replacement of large-sized plasma torches, Kuo[4] did his research in miniaturizing the existing plasma torches as shown in Fig. 1.

In the present work, the formation of jet flow, when jetting toward atmosphere through nozzle in accordance of producing swirl flow compulsorily through the change of inlet angle, is presented. In particular, the torch that has the longest throw length of jet at the constant flow rate while the swirl flow minimizes the resistance of inside wall of torches is to be investigated.

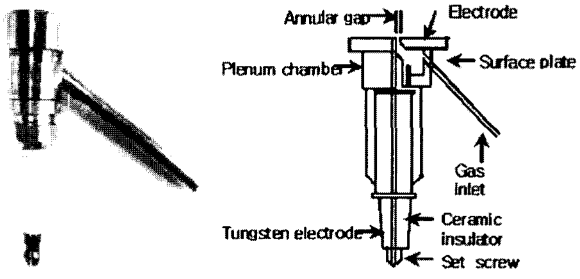


Fig. 1. Schematic of a plasma torch.

2. NUMERICAL ANALYSIS

2. 1 Governing Equations

In order to analyze the flow characteristics of a plasma torch, governing equations with continuity, momentum, energy and turbulent variables and can be expressed as follows:

$$\frac{\partial(\rho\phi)}{\partial t}+\nabla\cdot(\ \rho\phi\vec{V}\ )-\nabla\cdot(\Gamma_{\phi}\nabla\phi)\,S_{\phi} \qquad (1)$$

Here, Γ_{ϕ} is the effective diffusion coefficient and S_{ϕ} is the source term[5]. In this study, we also used standard model[6].

2. 2 Model and Grid System

Calculation model is used in size of practical torch as shown in Fig. 2. The calculation domain is composed to 60mm×60mm×80mm. For the formation of various swirl flows, two different angles are introduced; α is fixed to 30° and β is changed by 10° from 0° to 40°.

In order to elucidate the flow characteristics of plasma torch, three-dimensional grid system was made. Especially, the Cartesian cut-cell method was used[7]. This method is known as easier approach to solve this kind of complex geometry problem and to security convergent.

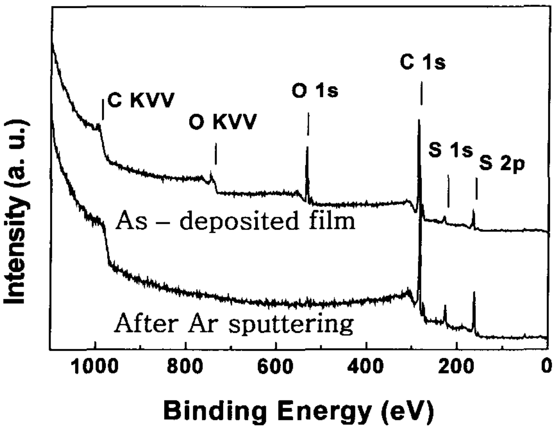


Fig. 2. Modeled torch and coordinates.

In this study, the geometry of plasma torch was created using three-dimensional CAD program. The grid system has 120×80×80 cells. The governing equations are solved using commercial code, PHOENICS-VR[8], which is providing the Cartesian cut-cell method with a personal computer (Pentium Ⅳ 1.8GHz CPU, 1GB memory). In addition, no-slip condition is used on the wall boundary. This is presumed that there is no mass flux on walls. In order to reduce a number of cells, the wall function was used. Also, Neumann condition that has zero gradient for all flow variables along streamline was applied on the outlet boundary, since the flow variables were difficult to know on the outlet boundary. For the numerical calculation, we used nitrogen as working fluid and 5m/s as inlet velocity.

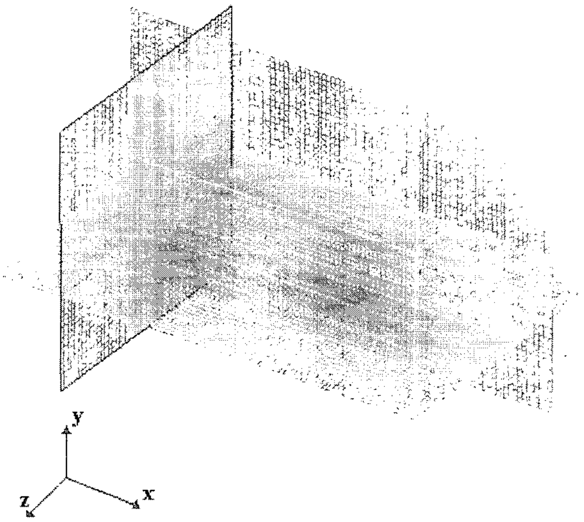


Fig. 3. Grid system (120×80×80).

3. RESULTS AND DISCUSSION

For analyzing the velocity distribution of a swirl flow inside the plasma torch and jet distance at atmosphere, the jet area and the whole size were fixed while the numerical analysis of $\alpha=30^\circ$ and $\beta=0^\circ$ was performed for the case of the nonoccurrence of swirl and the numerical analysis of $\beta=20^\circ$ was performed for the case of the occurrence of the swirl.

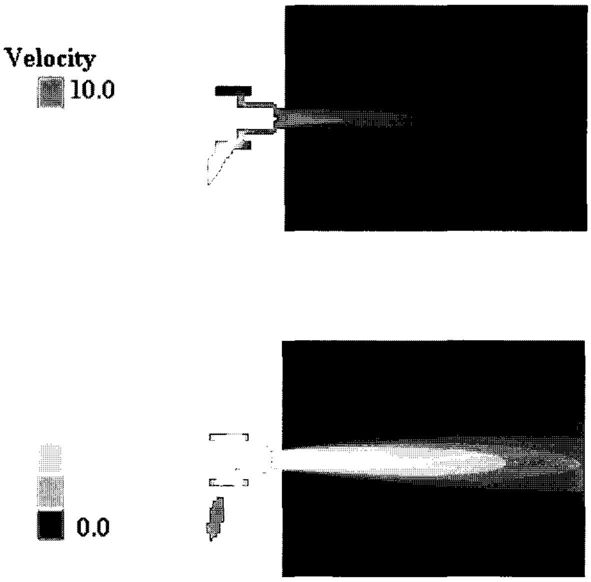


Fig. 4. Swirl effect on the velocity distribution.

The results show that the longer throw length of jet when the swirl was occurred as shown in Fig. 4. Also the distances at maximum velocity in the cases of the swirl and no-swirl are 23mm and 25mm, respectively, along the centerline (see Fig. 5). The maximum velocity with swirl has about 2.5 times that with the case of no-swirl.

For observing the flow direction in the case of swirl flow, each section is divided and the results of velocity distributions are shown in Fig. 6. In

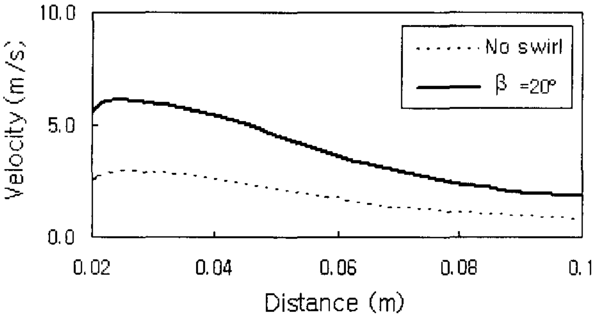
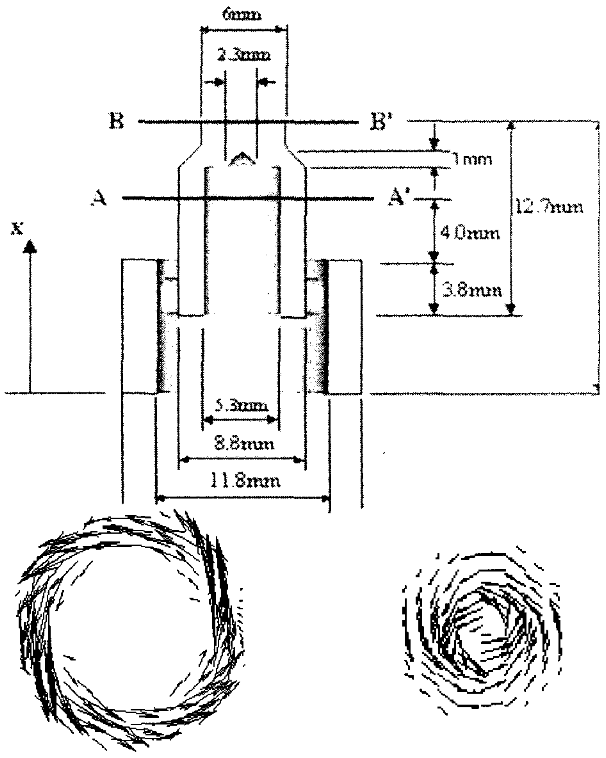


Fig. 5. Velocity distribution along the centerline (y=0).



a) A-A' section b) B-B' section

Fig. 6. Configuratiion of swirl flows.

order to elucidate the swirl effects, the formation of swirl on A-A′ and B-B′ sections are deficted. It is also noted that the formation of the swirl with inclining the inlet to the direction of β is the important factor that creates the maximum capacity of torches. In addition, to make a selection of optimum design through changed β, the numerical analyses are performed with various values of angle (β) which is increased by 10° from 0° to 40°.

It is seen that the most capacity of velocity distribution is occurred at $\beta=20°$ as shown in Fig. 7. This is explained as the degree of inlet angle (β) having the longest throw length of jet, and the formation of swirl flow is easy inside torches. In order to investigate quantitatively the above results, the velocity distribution along the centerline is presented in Fig. 8 with different inlet angles (β)

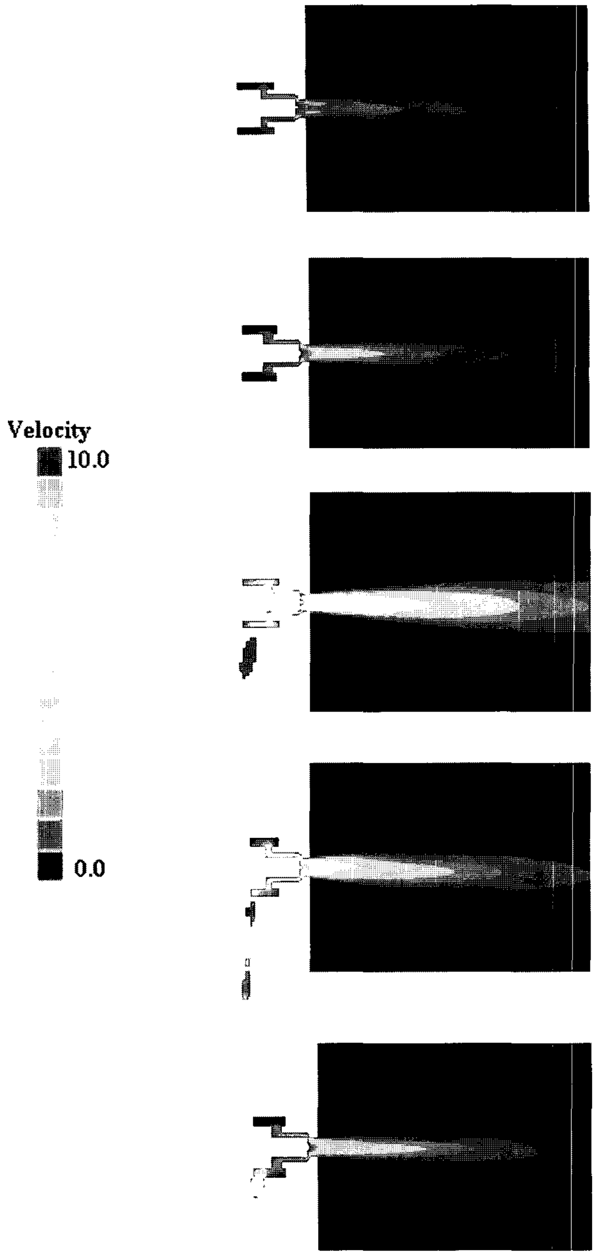


Fig. 7. Effects of inlet flow angle (β) on the velocity distribution (unit: m/s).

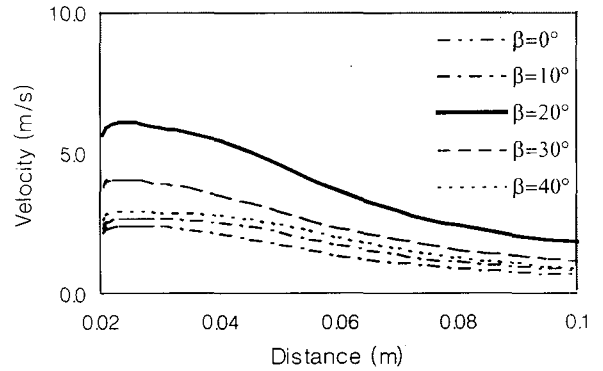


Fig. 8. Effects of inlet flow angle (β) on the velocity distribution along the centerline ($y=0$).

4. CONCLUSIONS

In this work, the effect of the swirl flow was studied numerically to design the optimal shape of atmospheric plasma torch. The major conclusions are as follows:

1) The method of vortex-stabilization is acquired by the occurred swirl flow.

2) Numerical analysis is performed with various inlet angles (β) to get optimum shape, which can minimize the resistance of inside wall of torches. Results show that the most optimized angle is derived at $\beta=20°$.

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REFERENCES

1. N. EI-Kaddah, J. McKelliget, J. Szekely, Heat Transfer and Fluid Flow in Plasma Spraying, Metal. Trans. B, 15B (1984) 59-70.
2. K.-D. Kang, S.-H. Hong, Arc Plasma Jets of a Non-transferred Plasma Torch, IEEE Tans. on Plasma Science, 24 (1996) 89-90.
3. D.-Y. Kim, L.-Y. Ko, Plasma Metal Eng., Bando, Seoul (1997).
4. S. P. Kuo., Koretzky, L. Orlick, Design and Electrical Characteristics of a Modular Plasma Torch, IEEE Tans. on Plasma Science, 27 (1999) 752-758.
5. S. V. Patankar, Numerical heat transfer and fluid flow, Hemisphere, Washington λ D. C. (1980).
6. H. K. Versteeg, W. Malalasekera, An Introduction to Computational Fluid Dynamics, Longman, London (1995).
7. G. Yang, D. Causon, R. Saunders, P. Batten, A Cartesian Cut Cell Method for Compressible Flows-part B: moving Body Problems, Aeronautical Journal, 101 (1997) 56-65.
8. Spalding, PHEONICS Encyclopedia, article on CFD to SFT, The status and Future of CFD, (1998).