

Fluid Flow Characteristics for Various Inflow in the Land Aquaculture

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Abstract: The aquafarm is a system used for breeding fish by using sea water. The main advantage of this paper presents the characteristics of fluid flow and temperature distribution at different plans in the aquafarm by the variations of inlet pipe position, inlet water temperature and flow rate. The paper aims to find an optimum combination of these factors which produces a velocity and temperature profile ideally suited for the breeding of a certain type of fish. The numerical analysis has been developed for calculating the velocity and temperature distributions in a rectangular model of an actual aquafarm scaled down by 25 times, the finite volume method and SIMPLE algorithm being used for the numerical analysis. The numerical model is based on the assumptions of steady state incompressible flow and uses 3-dimensional standard k- ϵ turbulence model. Experiments were also done. This experiments were compared with the results of numerical analysis showed good agreement.

Keywords: PIV(Particle Image Velocimetry), Standard k- ϵ turbulence model, FVM(Finite Volume Method)

1. INTRODUCTION

Nowadays our coasts have been damaged by the water pollution that resulted from the construction of industry on the shore, increasing population, and urbanization. As compared with the open sea, an inland sea has higher pollution level because of eutrophication and red tide. etc. Aquaculture, that raises aquatic products for eating, has generated many problems by destroying of an ecosystem.

The major environmental factors include water temperature, the amount of melted oxygen, salt, CO₂, ammonia, PH and nourished salt that are associated with the breeding of the aquaculture because it may have effects on the growth of the creatures and lead to their serious diseases.

In the Korean aquaculture industry, fisherman on the grounds prefer lefteye flounder (*Paralichthys olivaceus*) and rockfish (*Sebastes schlegelii*). The former is characterized by highly benefit and better returns, and the latter has advantage of raising the creatures. Nowadays, inland aquafarm uses recirculated sea water. This implies that to help quickly grow and to be strong enough to get over diseases needs to have much of melted oxygen, to have a better control on temperature. Therefore, recirculated seawater causes many problems. The major problem on this process is the increasing- cost of production and the disease to fish.

Several investigations of aquaculture in sea water have been reported. Kim(1997) examined the marine pollutions in biology point of view. This biological treatment has no problems in aquaculture industry

because the aquarium tank is separated from the water pollution. Partridge(1989) and Sannomiya(1987) examined the swimming structure and behavior of fish in aquarium tank. Takagi et al.(1993) considered the effect of the size and shape of aquarium tanks. Generally, the aquaculture equipment has two types of closed and open flow systems. Jeong et al.(1998) reported the flow characteristic by comparing numerical analysis and flow visualization images. Hirashi et al. (1995) examined the effect of water current in the aquaculture environment of the seas. The closed type is the system in which the sea water is recirculated again in the aquarium tank. The water in the case of the open flow system is discharged to the sea. Thus, the first system needs more expensive equipment, but this system can save on the energy for heating needed by the aquarium tank water in winter season. Lee(1994) carried out the experiment of a flow characteristics in the closed aquarium tank. In the design of an aquarium tank, what needs to be emphasized is the aquaculture environments. This means that the wrong design can cause the mass mortality of the breeding fish.

In this paper, we performed a numerical analysis for fluid flow characteristics in a land aquaculture tank is performed, and the numerical results are compared to the experimental results by visualization technique with PIV. This paper is intended as an investigation of the flow characteristics in an inland aquafarm, and will be focused on the distributions temperature and velocity.

2. STUDY METHOD

2.1 Experimental Study

Figure 1 shows the schematic diagram of the numerical analysis model. The geometry of an inland aquafarm model is $W \times H \times L = 0.2 \times 0.2 \times 0.04$ (m). This model consisted of one inlet and one outlet with the size of $d = 0.005$ m.

Figure 2(a) and (b) shows the photograph and schematic diagram of the experimental apparatus. The experimental test model has a tectangular type top opening which has rounded four corner. The top surface is opened with an outside temperature of 10°C . The working fluid used by water at 20°C and the incoming flow rate was set to 1.27×10^3 . The bottom and sidewalls were covered with black paint to achieve good particle image by CCD camera. The laser source was projected by an Argon-Ion laser with 490 mW.

Table 1 shows the condition of the present experimental study. The particle tracers are PVC (Poly Vinyl Chloride) and the average diameter is 200. The CCD camera, model CV-M50, was used for image capturing. The number of images is 200 frames to get an average image. The cross-correlation algorithm was adopted to calculate the coefficients from two consecutive images. 200 consecutive image frames were captured successively and digitized with a frame grabber into arrays of 640×480 pixels.

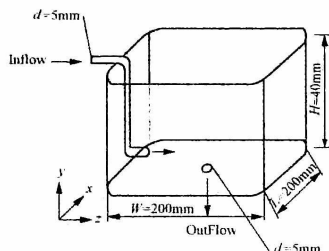
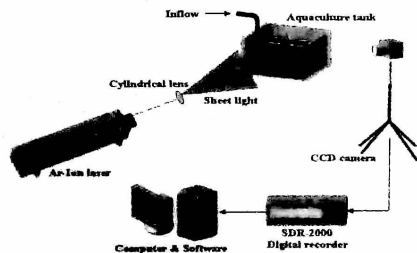
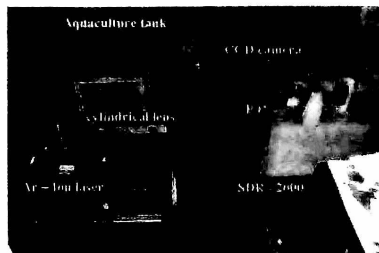


Figure 1: Schematic diagram for numerical model.



(a) Schematic diagram of experimental apparatus.



(b) Photograph of experimental apparatus.

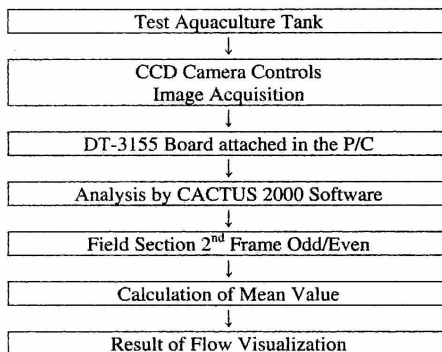
Figure 2: Schematic diagram and Photograph.

Table 1: Experimental conditions for PIV measurement.

Item	Specification
Image grabber	DT3155(640×480 pixel, B & W)
Light source	750mW, Ar-Ion Laser
Particle seed	PVC(Poly Vinyl Chloride : 200.)
Working fluid	Water(20 $^\circ\text{C}$)
Sheet light	Cylindrical Lens
Image recorder	SDR-2000
Computer	Intel Pentium III PC(800MHz)
Frame number for time-averaged	200 Frames
Identification	Two-Frame Gray-Level Cross Correlation Algorithm

2.2 Numerical Analysis

Table 2: Flow chart of PIV processing.



Three-dimensional incompressible steady-state Navier-Stokes equations were used to predict the internal flow and heat transfer characteristics. The standard $k-\epsilon$ turbulence model is generally used in the analysis of a turbulent flow field. The SIMPLE (Semi-Implicit Method for Pressure-Linked Equations) solution algorithm for correcting the pressure field was used, as explained in Patankar(1980).

This is mainly suitable for steady state flows and is stable for undistorted grid systems. Its virtue is that it is computationally efficient, generally requiring less CPU effort per iteration than other more hybrid schemes. At high Reynolds numbers the accuracy of the spatial discretization of convective fluxes is a determining factor for both calculation accuracy and stability.

The continuity and momentum equations can be described in Cartesian tensor notation as follows:

- Equation of continuity

$$\frac{\partial}{\partial X_j}(\rho u_j) = 0 \quad (1)$$

- Equation of momentum

$$\frac{\partial}{\partial X_j}(\rho u_i u_j - \tau_{ij}) = \frac{\partial P}{\partial x_i} + S_i \quad (2)$$

- Equation of energy

$$\frac{\partial(\rho U_j T)}{\partial X_j} = \frac{\partial}{\partial X_j} \left[\left(\frac{\mu}{P_r} + \frac{\mu_t}{\sigma_r} \right) \frac{\partial T}{\partial X_j} \right] \quad (3)$$

where ρ is the density of water and u_i is the velocity component. τ_{ij} and S_i denote the component of the stress tensor and momentum source respectively.

The particular high Reynolds number form the k- ϵ turbulence model used in the STAR-CD is 'appropriate', subject to the caveats given earlier, to fully turbulent, incompressible or compressible flows

The governing equations for turbulent kinetic energy and dissipation in the Standard k- ϵ turbulence model are as follows:

- Equation of Turbulent kinetic energy

$$\frac{\partial}{\partial u_j}(\rho \bar{u}_j k - \frac{\mu_{eff}}{\sigma_k} \frac{\partial k}{\partial x_j}) = \mu_i(P + P_B) - \rho \epsilon - \frac{2}{3}(\mu_i \frac{\partial u_i}{\partial x_i} + \rho k) \frac{\partial u_i}{\partial x_i} + P_{NL} \quad (4)$$

$$\text{where } P_{NL} = (\overline{u_i u_j} - 2s_{ij}) \frac{\partial u_i}{\partial x_j}$$

- Equation of Turbulence dissipation rate

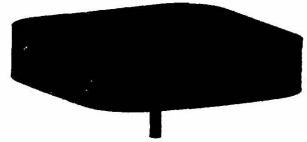
$$\begin{aligned} \frac{\partial}{\partial x_j}(\rho \bar{u}_j \epsilon - \frac{\mu_{eff}}{\sigma_k} \frac{\partial \epsilon}{\partial x_j}) = \\ C_{\epsilon 1} \frac{\epsilon}{k} \left[\mu_i(P + C_{\epsilon 3} P_B) - \frac{2}{3}(\mu_i \frac{\partial u_i}{\partial x_i} + \rho k) \frac{\partial u_i}{\partial x_i} \right] \\ - C_{\epsilon 2} \rho \frac{\epsilon^2}{k} + C_{\epsilon 4} \rho \epsilon \frac{\partial u_i}{\partial x_i} + C_{\epsilon 1} \frac{\epsilon}{k} P_{NL} \end{aligned} \quad (5)$$

where σ_k , $C_{\epsilon 1}$, $C_{\epsilon 2}$, $C_{\epsilon 3}$ and $C_{\epsilon 4}$ are empirical coefficients whose values, taken from references, are given in Table-3. The right-hand side terms represent similar effects to those described above for the k equation.

Table 3: Values assigned to standard k- ϵ turbulence model coefficients.

C_μ	0.09	$C_{\epsilon 4}$	-0.33
$C_{\epsilon 1}$	1.44	σ_k	1.0
$C_{\epsilon 2}$	1.92	σ_ϵ	1.22
$C_{\epsilon 3}$	0.0 or 1.0	σ_h	0.9

The incoming Reynolds number is set to 2.108×10^3 . The incoming temperature and atmosphere temperature are set to 293K and 283K, respectively. The vertical velocity was assumed to be 0, and turbulence intensity is set to 5% uniformly. The dynamic condition near the walls used wall function and adiabatic condition. The heat flux is set to $-20W/m^2$.



(a) Geometry of inland aquafarm.



(b) Computational grid system of inland aquafarm.

Figure 3: Geometry and grid system for numerical analysis.

3D model calculation was performed using CATIA, and PRO-AM was used to create the lattice. The total number of lattices used for numerical modeling is 60,000. Actual calculation of the model used the common CFD code, STAR-CD ver-3.15A. Figure 3(a) shows the measurement of inland aquafarm. The grid system of the numerical model is shown in Figure 3(b). The calculation is repeated at steady state, and the iteration was assumed to be converged when the residual value of the dependent variables was 10^{-3} or less.

3. RESULTS & DISCUSSIONS

3.1 Comparisons of the experimental and numerical results

The general breeding fish inhabit near the bottom of a land aquaculture tank. The velocity distributions near bottom wall were selected as a horizontal plane. Figure 4 and 5 represent the velocity vectors between the experiment and numerical results. The experimental and numerical results are compared base on velocity difference according to X-Z plane at $Re = 1.27 \times 10^3$.

Figure 4 shows each inlet fluid flow characteristics and the time-averaged velocity vectors at the experimental results. Aquarium tank depth is set to 10mm, 25mm and 35mm. The entire flow pattern has a swirling flow pattern. The unique flow pattern appeared at near center. Velocity magnitude of this flow is decreased because the depth of the aquarium tank is shallow, and the velocity magnitude of walls is

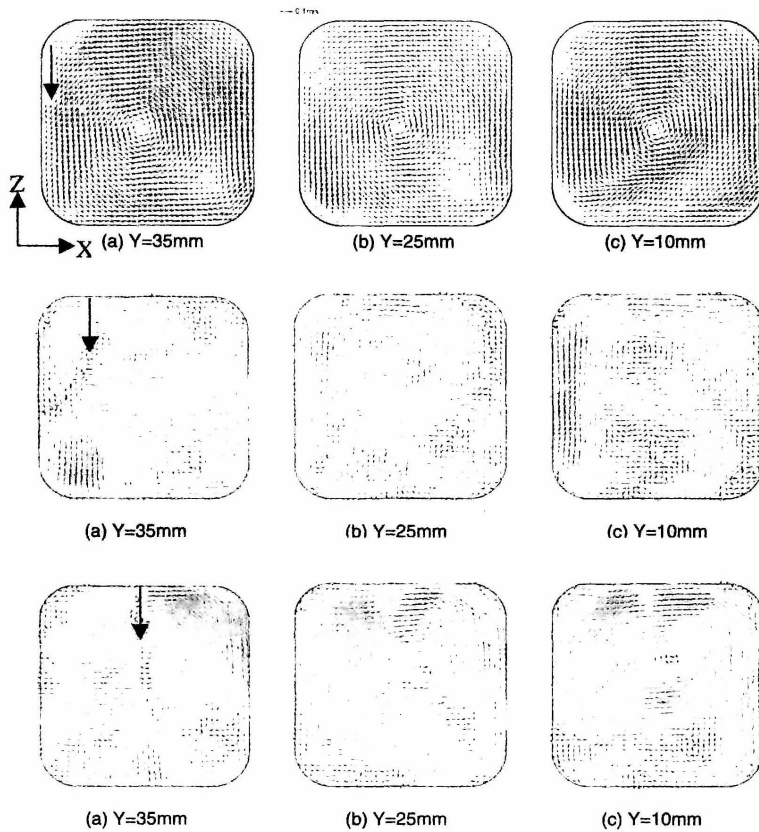


Figure 4: Distributions of Velocity vectors for experimental results at X-Z plane, $Re=1.27 \times 10^3$.

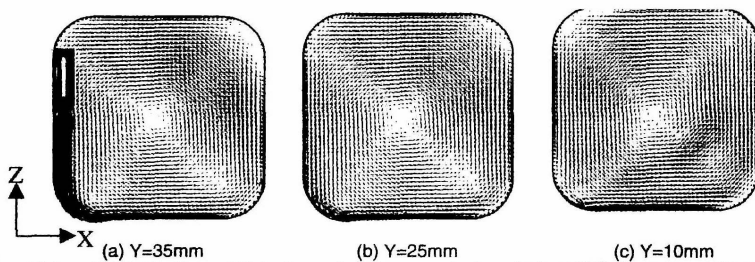


Figure 5: Distributions of Velocity vectors for numerical analysis at X-Z plane, $Re=1.27 \times 10^3$.

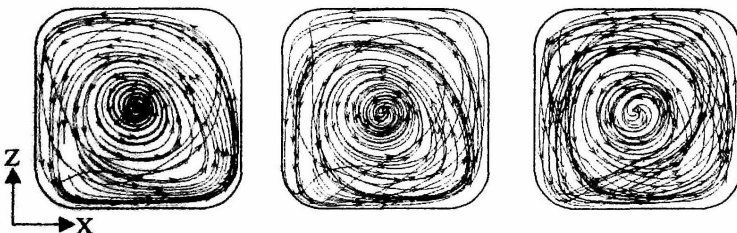


Figure 6: Particle tracking for numerical analysis at X-Z plane, $Re=2.12 \times 10^3$.

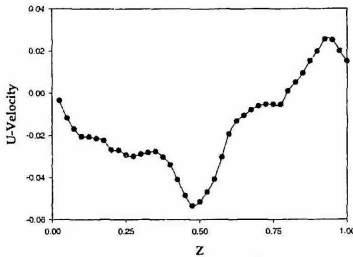


Figure 7: Velocity distributions with $Re=1.27 \times 10^3$ at $X=100\text{mm}$ and $Y=10\text{mm}$

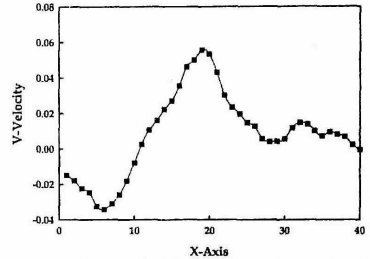


Figure 8: Velocity distributions with $Re=1.27 \times 10^3$ at $Z=100\text{mm}$ and $Y=25\text{mm}$.

decreased by friction. Fig 4(b) shows the stagnation region at the corner of the right side. This is because of the increased fluid velocity on the Y-axis (depth direction) by X-Z plane at $Re=1.27 \times 10^3$. As the depth of aquarium tank is shallow, the stagnation region is decreased at the aquarium tank.

Figure 5 shows the time-averaged velocity vectors at the numerical analysis results. Figure 5(a) shows that the velocity increases near the inlet. This is because the inlet velocity by streamed a narrow pipe. Results of this section, the velocity values have some difference between the experiment and the numerical

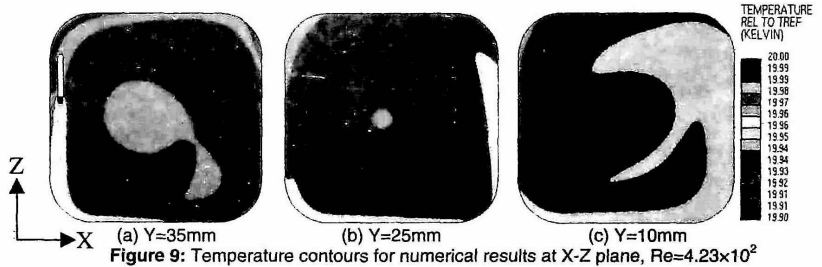


Figure 9: Temperature contours for numerical results at X-Z plane, $Re=4.23 \times 10^2$

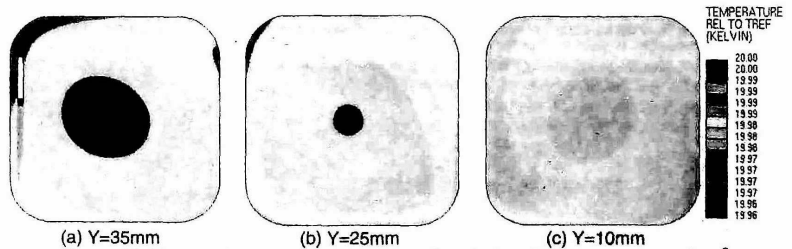


Figure 10: Temperature contours for numerical analysis at X-Z plane, $Re=1.27 \times 10^3$

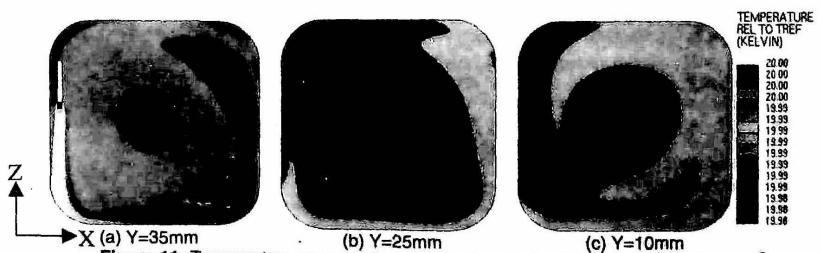


Figure 11: Temperature contours for numerical analysis at X-Z plane, $Re=2.12 \times 10^3$

analysis results. The reason for this difference is considered to be the PIV resolution errors because of high velocity around the inlet. In order to clarify the applicability of the foregoing numerical analysis, comparative studies with the experimental results have been carried out in an inland aquafarm model, and the calculated results had good agreements with the experiment.

Figure 6 shows the particle tracking at each section. The apparent swirl motion is observed in each section of the aquarium tank. As the depth is deeper, the swirl motion is advanced to right side the corner by outlet flow velocity. Consequently, when the depth is 10 and 25mm, the flow at near bottom wall can not be shown as the stagnation region. Therefore, this region can not cause the stagnation of pollutants and excrements, etc..

3.2 Temperature distributions of numerical analysis

As mentioned above, this study analyzes and verified the flow field in an inland aquafarm model. One of the main purposes of this study is to obtain the flow and temperature profile in the actual aquaculture tank. In the aquaculture industry, the optimum temperature for breeding fish is about 20°C in winter season. Thus, in this study, the size of the aquarium tank for calculation was set to the same conditions. In the case of an actual aquarium tank for breeding fish, the aquarium tank depth is not over 40mm. Therefore, the aquaculture tank depth selected was between 10 to 35mm in this study. The costly breeding of fish in aquarium tanks behave at near bottom of tank. Thus, the main flow characteristics were focused near the bottom in X-Z plane, Y=10mm.

Figure 7 shows distributions of velocity with $Re=1.27 \times 10^3$, at X=100mm and Y=10mm. Figure 8 shows distributions of velocity with $Re=1.27 \times 10^3$, at X=100mm and Y=25mm. The counterclockwise rotation vortex was formulated at the center point on the same streamline pattern.

Figure 9 ~ Figure 11 shows the distributions of temperature by each section according to the Reynolds number. Reynolds numbers at the inlet are selected as, 4.23×10^2 , 1.27×10^3 and 2.12×10^3 .

The high temperature appears near each wall of the X-direction and Z-direction, and this high temperature is distributed widely in the plane by the swirling flow. As the tank depth deepens, the high temperature can be propagated to other regions.

4. CONCLUSION

In order to verify the calculation code, the numerical analysis and experimental PIV data were compared in the aquaculture tank model. Based on this calculation code, the flow field in the aquaculture tank was carried out for various tank geometries. Some important results can be summarized as follows.

1. Inlet flow close by z-direction maintains normal fluid than different type.

2. The comparative studies with experimental results have been carried out, and the calculation results had good agreements with the experiment.

3. When the depth of the aquarium tank becomes deeper, the flow field near the bottom wall was advanced with stable flow.

4. As the depth of the aquarium tank is deeper, the high temperature appeared near the wall in the X-direction and Z-direction, and this high temperature is distributed widely due to large swirling flow.

5. The temperature in the aquarium tank is increased when the inlet velocity increases.

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REFERENCES

- [1] Kim, H. G. 1997, Recent Harmful Algal Blooms and Mitigation Strategies in Korea. Ocean Research, Vol 19(2), pp185-192.
- [2] Partridge, B. L., 1989, The Structure and Function of Fish School, Sci. Am., 246, pp90-99.
- [3] Sannomiya, N. and Matuda, K., 1987, Least Squares Estimation in Fish Behavior Model, Bull. Japan. Soc. Sci. Fish., 53, pp1951-1957.
- [4] Tsutomu Takagi, Kausuaki Nashimoto, Katsutaro Yamamoto and Tomonori Hiraishi 1993, Kang, W. J., Cho, S. S., Huh, H. and Chung, D. T., 1998, Identification of Dynamic Behavior of Sheet Metals for an Auto-body with Tension Split Hopkinson Bar, SAE 981010, pp115-119.
- [5] Jeong, H. M. and Chung, H. S., 1998, Study on Fluid Flow Characteristics of Aquarium for Optimum Environment, Air-Conditioning and Refrigeration Engineering., 10, 1, pp108-117.
- [6] Tomonori Hiraishi, Karsuaki Nashimoto, Tsutomu Takagi, Kengo Suxuki and Keiichi Moromatu, 1995, Stationary Ability of Bastard Halibut *Paralichthys olivaceus* and Longsnout Flounder *Limanda punctatissima* to Water Current at the Bottom of a Net Cage, Bulletin of the Japanese Society of Scientific Fisheries, 61, 3, pp363-368.
- [7] Lee, J. S., 1994, Hydraulic Studies on Recirculating Aquaculture Basin, J. Korean Fish. Soc, 27, 2, pp173-182.
- [8] Jones, W. P. and Launder, B. E., 1973, The Calculation of Low-Reynolds-Number Phenomena with a Two-Equation Model of Turbulence, Int. J. Heat Mass Transfer, 16, pp1119-1130.
- [9] Patel, V. C., Rodi, W. and Scheuerer, G., 1985, Turbulence Models for Near-Wall and Low Reynolds Number Flows, A Review, AIAA J., 23, 9, pp1308-1319.
- [10] Seo, H. T., Lee, D. S., Yoon, S. H. and Boo, J. S., 1998, Numerical Analysis on Wall Attaching Offset Jet with Various Turbulent k-ε Models and Upwind Scheme, Trans. Of KSME, Part B, pp828-835.
- [11] Patankar, S. V., 1980, Numerical Heat Transfer and Fluid Flow, Hemisphere Publishing corporation, McGraw-Hill, New-York.
- [12] Daichin and Lee, S. J., 2003, Evaluation of Recursive PIV Algorithm with Correlation Based Correction Method Using Various Flow Images, KSME International Journal, 17, 3, pp409-421.