Performance Prediction of Impulse Turbine for Wave Energy Conversion

-Effect of Simple Cascade on the Performance-

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***Abstract*—Wave energy can be converted into electrical energy by using a wave energy converter. The oscillating water column (OWC) based wave energy converter is one of the most useful device because of its simple structure and easy handling features. The water column in an air chamber oscillates in accordance with the surrounding ocean wave, and results in an alternating airflow inside the chamber. The airflow then rotates an air turbine connected to a generator. The authors have developed an impulse turbine that rotates to the perpendicular direction of alternating airflow. The turbine has two rows of guide vanes, and one rotor between them. The blade profile is formed by the combination of a circle and an ellipse. In the present study, a simple turbine cascade was employed as a purpose of reducing the manufacturing cost, and the performance of turbine with simple cascade was investigated using the computational fluid dynamics (CFD) analysis. Results are compared with the experimental data.**

***Keywords*— Wave energy conversion, impulse turbine, bi-directional flow, OWC, CFD.**

I. INTRODUCTION

Oscillating water column (OWC) principle is a method of acquiring the energy of waves in the ocean. Figure 1 shows the schematics of OWC devic, and it is one of the most useful device because of its simple structure and easy handling features.

The impulse turbine is used to harness the pneumatic energy of alternating airflow in the OWC system [1]-[3]. This turbine has two rows of guide vanes, and one rotor between them as shown in Fig. 2 (a). The main advantage of this turbine is high efficiency in a wide range of flow rates.

In the present study, the cascade configuration was modified to a simple cascade in order to investigate its effect on the turbine performance. Circular and elliptical blades which are the blade profiles of original turbine were proposed as the simple cascade. The work was conducted using the CFD analysis, and the obtained results were compared with the experimental data.

II. METHODOLOGIES

Figure 2 (a) shows the specification of original impulse turbine. The rotor details are as follows: ratio of blade thickness, 0.3; chord length, 54mm; rotor inlet and outlet angle, γ=60˚; tip diameter, 299mm; hub diameter, 210mm; mean radius R=127.5mm; hub-to-tip ratio, ν=0.7. The specifications of guide vane are as follows: chord length, 70mm; setting angle, θ=30˚; blade thickness, 2mm. The adopted turbine rotor and guide vane were reported as the most promising one in previous studies (e.g. [1]).

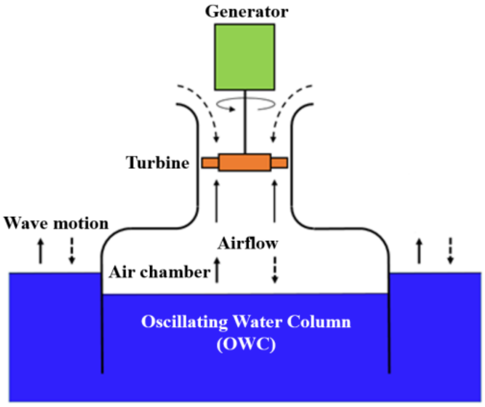
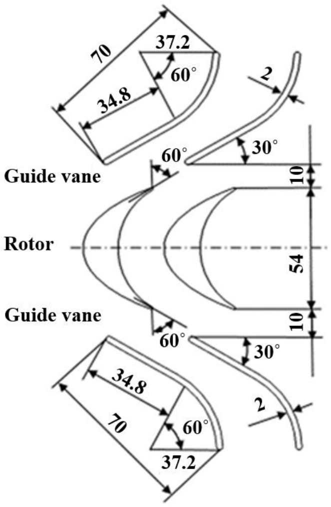
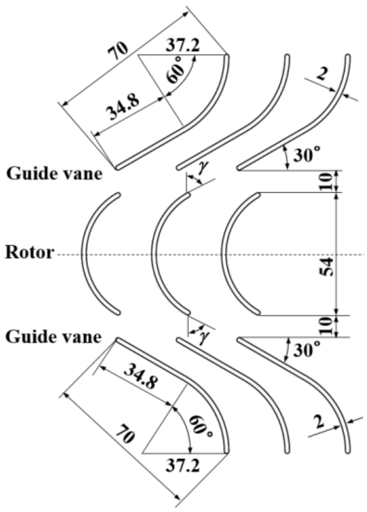


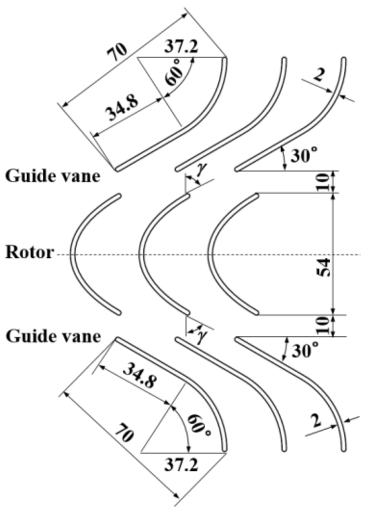
Fig. 1 A schematics of wave energy converter with OWC



(a) Original blade



(a) Circular blade



(b) Elliptical blade

Fig. 2 Specification of tested turbines

TABLE I Specification of tested blades

γ °	
Circular blade	Elliptical blade
60	60
70	70
80	80
90	
100	

As shown in Fig. 2 (b) and (c), the specification of simple cascade of impulse turbine. The detail specifications are as follows: ratio of blade thickness, 0.3; chord length, 54mm; rotor inlet and outlet angle, γ; tip diameter, 299mm; hub diameter, 210mm; mean radius R=127.5mm; hub-to-tip ratio, ν=0.7. The setting angle of guide vane of θ=30˚ was adopted, because that guide vane specifications are the same as the original turbine. Rotor inlet and outlet angle γ was changed in increments of 10˚ as shown in TABLE I.

The numerical analysis was conducted a commercial CFD tool of SCRYU/Tetra that is developed by Cradle Co., Ltd. The computational domain was composed of about 7,000,000 mesh elements. The Reynolds averaged Navier-Stokes equations were used as the governing equations, and the SST k-ω model was used to predict the turbulent stresses. The flow was considered as steady flow, and the non-slip boundary condition was applied to the solid boundaries. The flow rate at the inlet was kept constant at Q=0.320m^3/s. The outlet was opened to the atmosphere. Turbine rotation was modelled by the steady Arbitrary Lagrange-Eulerian (ALE) method. Tip clearance was ignored in order to cut of the computational cost.

III. Evaluation Formulae

The turbine performance under steady flow conditions was evaluated by the torque coefficient C_T, input coefficient C_A, flow coefficient ϕ, and efficiency η. The definition of these parameters are as follows:

$$C_T=T_o/\{\rho(v^2+u^2)AR/2\} \quad (1)$$

$$C_A=T_o/\{\rho(v^2+u^2)Av/2\}=\Delta p/\{\rho(v^2+u^2)/2\} \quad (2)$$

$$\eta=T_o\omega/(\Delta pQ)= C_T/(C_A\ \phi) \quad (3)$$

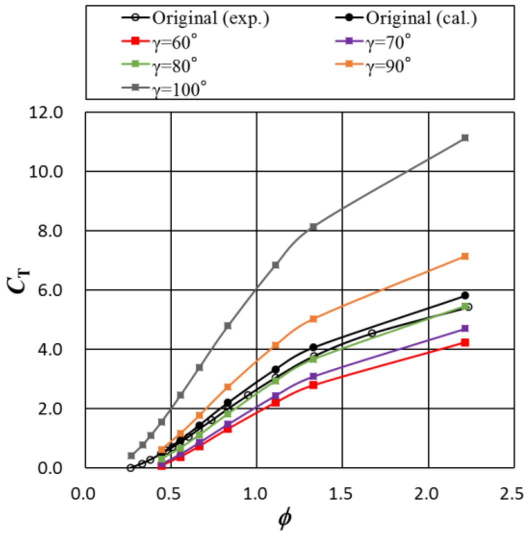
$$\phi=v/u \quad (4)$$

where A, u, v and ρ denote the flow passage area $\{=\pi D^2(1-\nu^2)/4\}$, circumferential velocity at mean radius (=$R\omega$), axial flow velocity (=Q/A) and density of air, respectively.

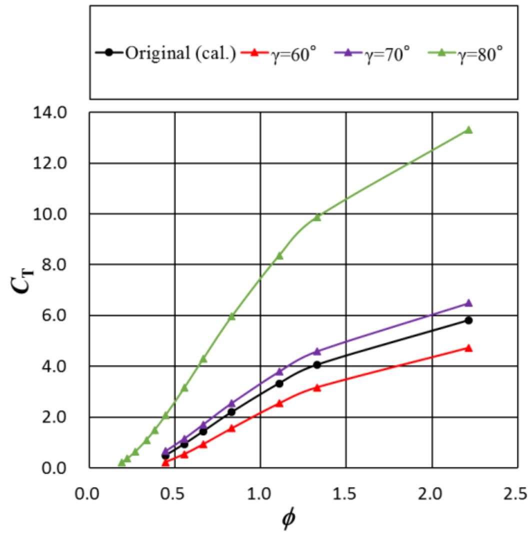
IV. Results And Discussion

Since the experimental data of simple cascade impulse turbine has not yet been published, the experimental data of the impulse turbine (the turbine specification is same as of the present turbine) was used to validate the CFD works.

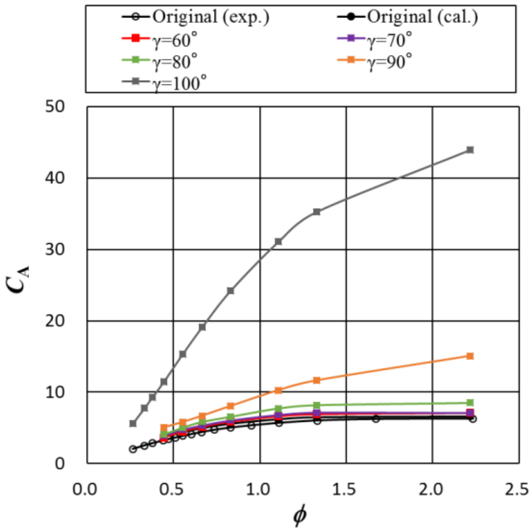
The comparison between the experimental and computational results of turbine torque coefficient C_T, input coefficient C_A and efficiency η are shown in Fig. 3. The predicted C_T, C_A and η show a good agreement with the experimental results. Thus, it can be mentioned that the present CFD model is good enough to predict the flow features.



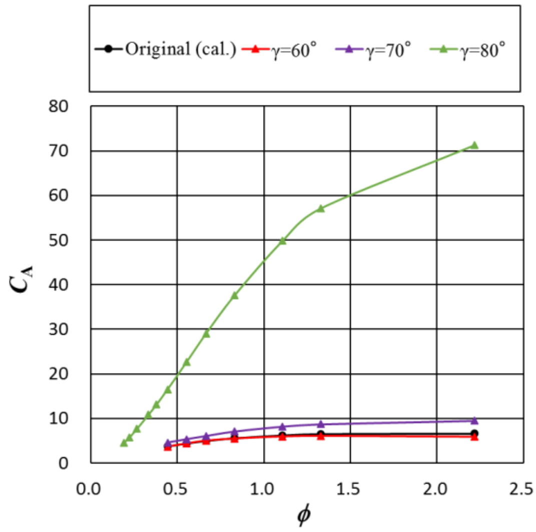
(a) Torque coefficient



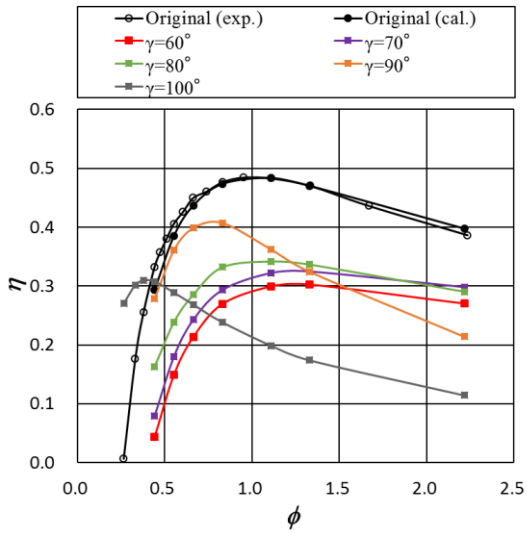
(a) Torque coefficient



(b) Input coefficient

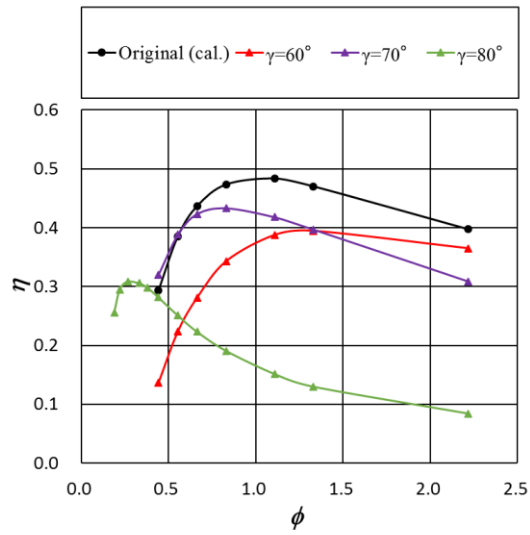


(b) Input coefficient



(c) Efficiency

Fig. 3 Effect of circular blade on turbine characteristics



(c) Efficiency

Fig. 4 Effect of elliptical blade on turbine characteristics

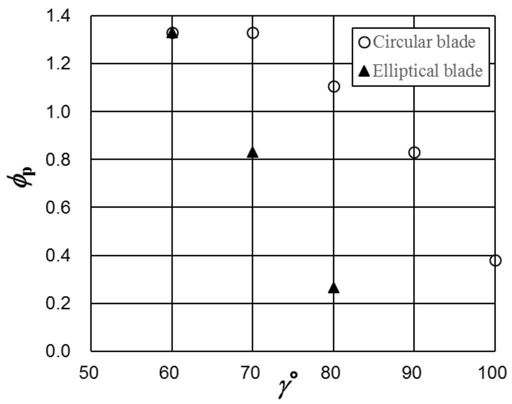


Fig. 5 Effect of rotor inlet and outlet angle of simple cascade turbine on the peak efficiency point

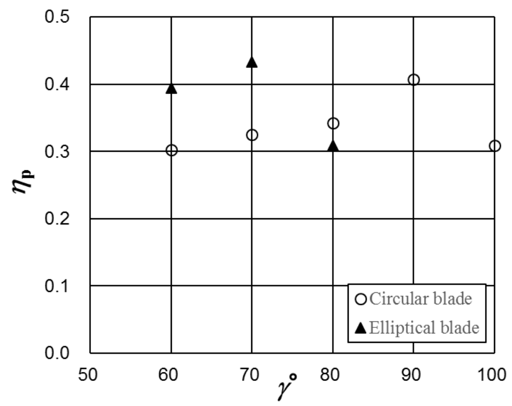


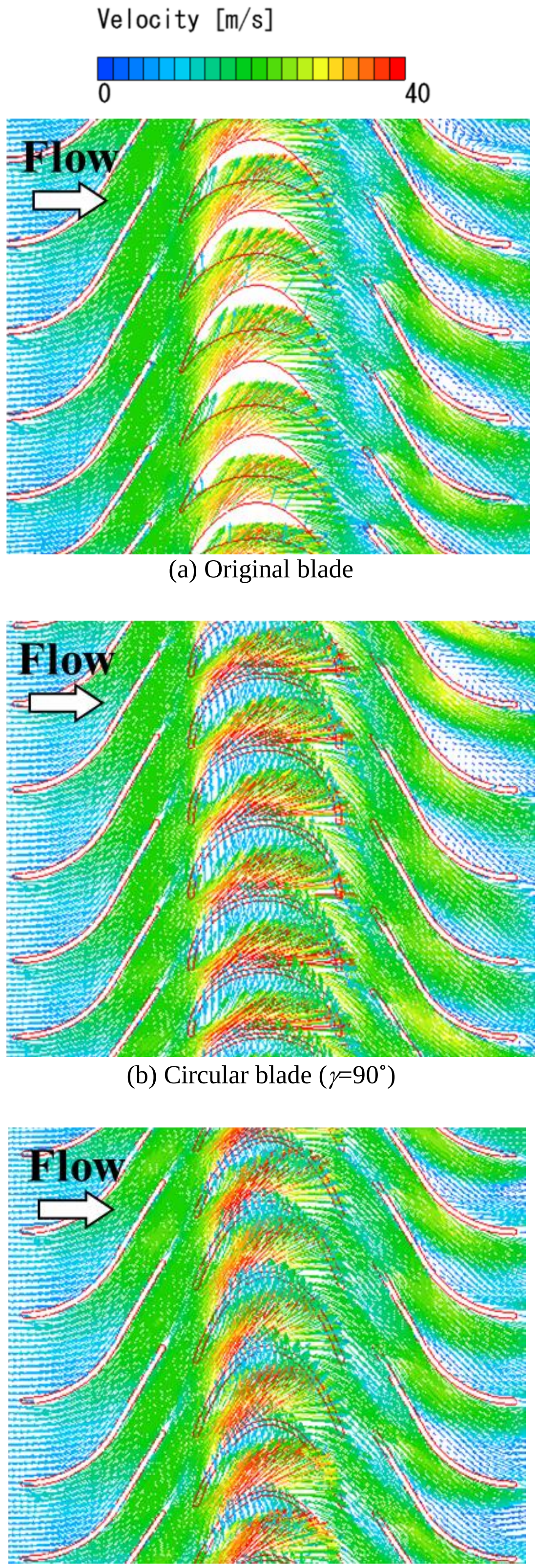
Fig. 6 Effect of rotor inlet and outlet angle of simple cascade turbine on the peak efficiency

Figure 5 shows the effect of rotor inlet and outlet angle of simple cascade turbine on the peak efficiency point ϕ_p. From this figure, as the angle γ increases it decreases the peak efficiency point. This phenomenon is caused by the decreasing of collision losses on the suction surface.

Figure 6 shows the effect of rotor inlet and outlet angle of simple cascade turbine on the peak efficiency η_p. The peak efficiency of each turbines increases as γ increases. The suitable values of γ at the highest efficiency are as follows: circular blade, γ=90˚; elliptical blade, γ=70˚.

The velocity vectors at mean radius of the turbine are shown in Fig. 7. The velocity vectors in original impulse turbine are along the blades. However, a low velocity distribution occurs around the pressure surface of circular and elliptical blades. It seems that a separation vortex occurs on the pressure surface.

As shown in Fig. 8, the flow collision occurs on the suction surface in all type of turbines. In the cases of circular and elliptical blades, high-pressure distribution is shown on the pressure surface at the downstream side. It is guessed that the flow collides with the pressure surface at the downstream side.

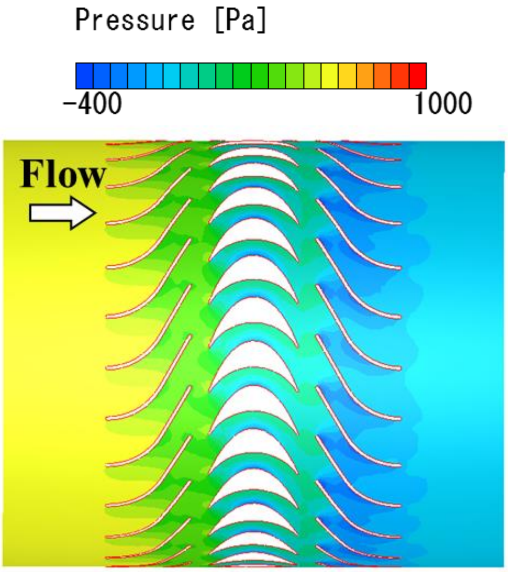


(a) Original blade

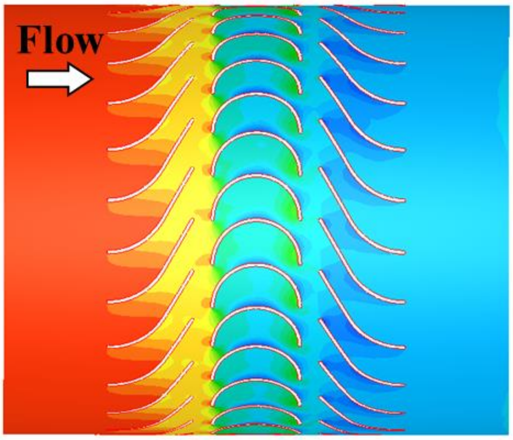
(b) Circular blade (γ=90˚)

(c) Elliptical blade (γ=70˚)

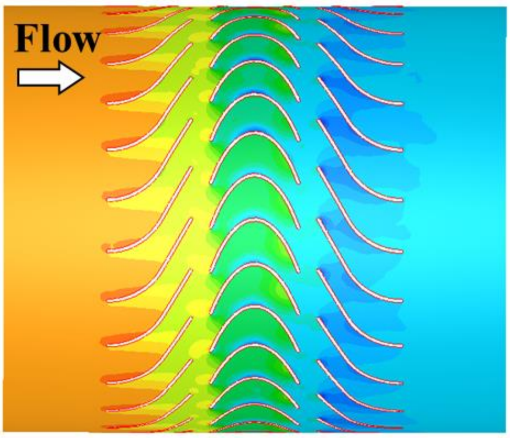
Fig. 7 Velocity vectors at mean radius (ϕ=0.83)



(a) Original blade

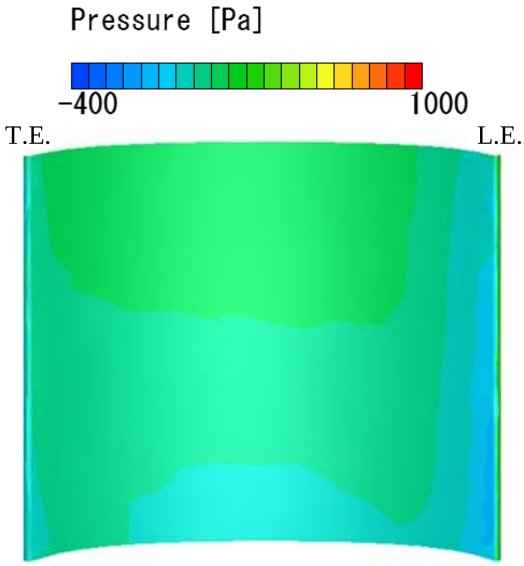


(b) Circular blade (γ=90˚)

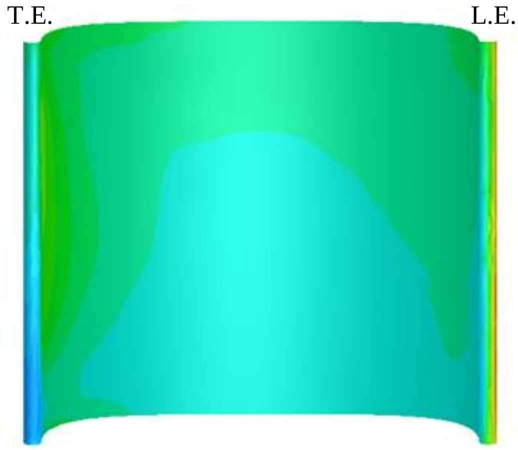


(c) Elliptical blade (γ=70˚)

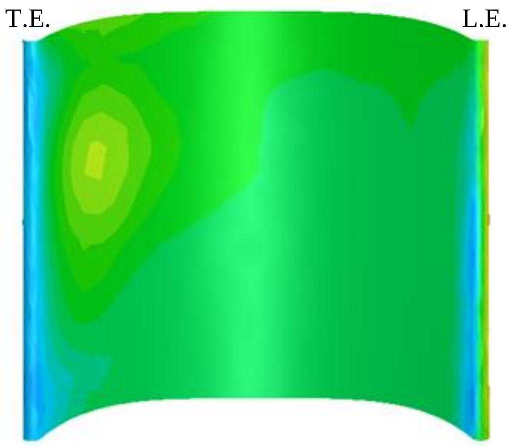
Fig. 8 Pressure distribution at mean radius (ϕ=0.83)



(a) Original blade

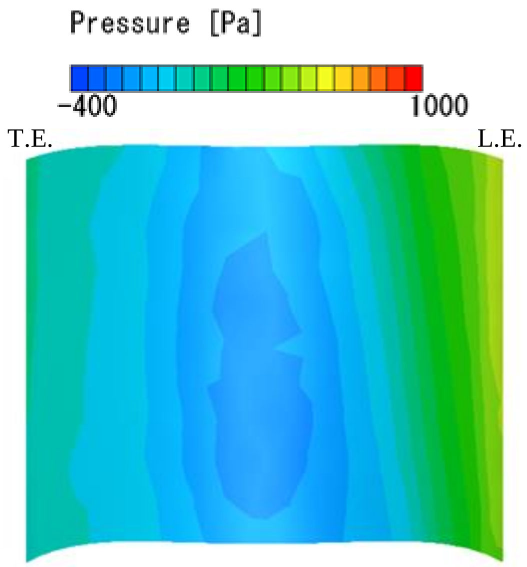


(b) Circular blade (γ=90˚)

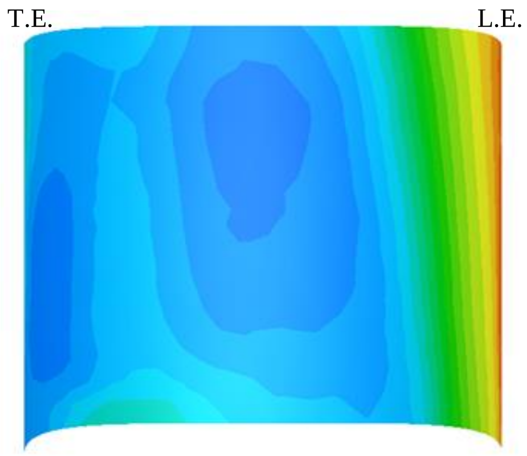


(c) Elliptical blade (γ=70˚)

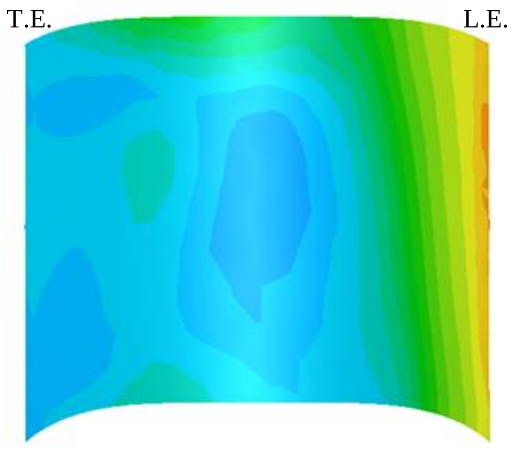
Fig. 9 Pressure distribution on pressure surface (ϕ=0.83)



(a) Original blade



(b) Circular blade (γ=90˚)



(c) Elliptical blade (γ=70˚)

Fig. 10 Pressure distribution on suction surface (ϕ=0.83)

Figure 9 shows the pressure distribution on pressure surface. A high pressure point is shown on the pressure surface near trailing edge of elliptical blade. It appears that separation vortex is occurred on the pressure surface near trailing edge.

Pressure distributions on the suction surface are shown in Fig. 10. High pressure points are shown at trailing edge of circular and elliptical blades. Moreover, the pressure around the leading edge is decreased for circular blade.

V. CONCLUSION

In the present study, the rotor and guide vane rows of impulse turbine for wave energy conversion were modified to a simple cascade. A CFD work was conducted to investigate its effect on the turbine performance. The following results are obtained:

(1) The efficiency of turbine with simple cascade reaches over 40%.

(2) The suitable value of inlet and outlet angle for circular and elliptical blades are 90˚ and 70˚, respectively.

Since the guide vane geometry was not changed in this study, the effect of guide vane setting angle is to be investigated in a future work.

ACKNOWLEDGMENT

This research is supported by the Japan Society for the Promotion of Science (JSPS) as Grant-in-Aid for Scientific Research (B) (No.16H04607). The authors wish to thank JSPS for their financial support in conducting this work.

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