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Numerical simulation of a novel ocean wave energy converter

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Abstract

Ocean waves are one of the energy resources, which have a potential to supply some parts of the world's energy requirements. Recently, many researchers are interested in investigation of the ocean wave energy conversion (OWEC), because energy generation from this device is considered renewable and clean energy. A new wave energy converter named "Searaser" was invented with new technology in 2013. The primary aim of this research is to study the capability of *Flow*-3D commercial software in simulation of this energy converter. In order to validate the results, a comparison was made between numerical and experimental research, which showed a good agreement in motion of buoy. In this research, wave energy converter was simulated inside a wave tank including water. Furthermore, Reynolds Averaged Navier-Stokes equations were coupled with volume of fluid (VOF) model to generate three-dimensional numerical linear propagating waves as well as solving the fluid flow. Pressure and velocity contours were shown when wave passes the buoy. Although different methods are used for mesh generation of solid and fluid domains in this software, results indicate the capability of *Flow*-3D software for modelling the fluid structure interaction (FSI) problems including wave motions. However, more parametric studies need to be conducted for this new energy converter to illustrate more details about the power generation of this energy converter.

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Keywords: Searaser; ocean wave energy converter (OWEC); computational fluid dynamics (CFD); renewable energy

1. Introduction

Fossil fuels as the major source of energy have several disadvantages like environmental hazards, rising prices, climate change. On the other hand, renewable energies such as ocean wave energy, solar energy, and wind energy are sustainable sources, which will never run out. Furthermore, these types of energy sources generate electricity without producing any hazardous products such as carbon dioxide (CO_2) or any other chemical pollutants; hence, they can supply the worldwide demands of electricity. In recent years, the wave energy as a renewable energy has gained the attraction of many researchers and companies due to its incredible advantages. Wave energies have several benefits in comparison with other renewable energies, for instance they are more available, predictable, and higher energy densities, which can produce more power with lower cost. Over the past decades, numerical techniques have been used to simulate different types of engineering problems including turbomachinery [1–9] and heat transfer [10–14] which the results have shown good agreements with experimental tests. Therefore, numerical approach has been employed in this paper to simulate the motion of a novel energy converter called "Searaser" [15].

In general, there are different types of wave energy converter (WEC) systems. WEC is categorized in four different groups including oscillating water column, overtopping device, attenuator, and point absorber [16]. Diego et al. [17] compared the result of this innovative WEC with traditional rubble mound overtopping device, and they proposed new formulae for hydraulic performance and loading on the front reservoir. There are many numerical and experimental researches on different common types of energy converters [18, 19]. To produce considerable energy, point absorbers can be attached to each other in parallel or series forms [15, 20]. Pelamis is a snake-like device that consists of cylindrical bodies connected together. Furthermore, there are other famous attenuators such as Wave Star [21], Salter Duck [22] and Anaconda [23]. Recently, many researchers are interested in minimizing the energy consumption and cost [24–28], which can be done some financial calculation for point absorbers as well. Although many research has carried out on these devices, using numerical simulation to measure hydro-acoustic of energy converters are necessary due to its dangers ocean animals. So far, many researches have used numerical technique to calculate the noise for different engineering problems [29–32].

In 2013, a novel OWEC named "Searaser" was invented [33] based on the registered patent. According to the inventor's patent, this invention has exceptional benefits in compared with other type of OWECs. In the current study, the performance of Searaser in a wave tank was studied by solving Navier-Stokes equations. Hence, a commercial computational fluid dynamics (CFD) code (*Flow*-3D) which is appropriate for numerical modelling of WEC has been used to solve the governing equations.

2. Description of Searaser

This novel technology named "Searaser" which can be used as a water pump to generate electricity was invented by Alvin Smith and registered as a patent [33]. Indeed, Searaser is a new device in order for utilizing hydro-power as a renewable energy source. As shown in Fig. 1, it consists of a cylinder attached to a piston, which is forced upwards by the buoyancy force since it is floating on the water surface when the ocean waves approach the device. Afterward, the gravity force of body overcomes other forces such as dynamic forces and wall friction after passing waves, and it causes to move buoy downward gradually. This device employs the periodic motion of waves to pump the ocean water to higher level (on-shore) in order to store it in large ponds and generate electricity with a turbine and generator on demand. Searaser has many notable advantages which some of them are mentioned here. Firstly, the price of components decreases because the components producing electricity (turbine and generator) are separated from Searasers while generating electricity on the ocean surface requires the special components due to the corrosion. Secondly, producing electricity by Searaser is obviously considered clean energy since there are no climate gas emissions involved (at least not after construction and installation). As another benefit, it has a simpler design and cheaper components than other wave energy converters, which make this invention especial. Additionally, the output water from this device can be transferred to the allocated area designated for the off shore wind turbines and it helps to create a more effective area.

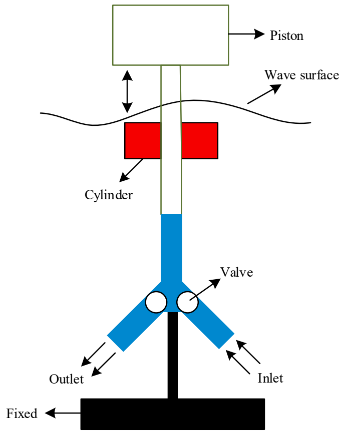


Fig. 1. Schematic view of different components of a Searaser.

3. Modelling

In this study, Alvin Smith's second scheme (modified model) was chosen for simulation including 4 main bodies as follows.

3.1. Buoy

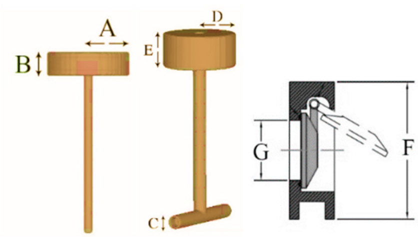
The buoy radius and height are A = 2.6 m and B = 1.5 m, respectively. This buoy is inserted 10.1 m deep in the pumping duct. The radius of this part is considered equal to radius of the pumping case to prevent leakage from the edges. As shown in Fig. 2(a), the buoy is not completely filled and a cylindrical space with the radius of 2.3 m and height of 0.5 m is extracted from the buoy. As the buoy should overcome the water column and also push the accumulated water, the net weight of this buoy is 9000 kg. In order to build this equipment, specific composite material is usually utilized to prevent the corrosion caused by water; also the buoy should be filled with sand, water to have the reasonable weight since the composites are lightweight. Furthermore, the buoy was designed to be capable of moving only in vertical direction (the gravity direction) because the vertical duct does not allow it to move toward other directions.

3.2. Chamber

According to the Fig. 2(b), the second part is a chamber including inlet and outlet valves with diameter of C = 0.536 m. The radius and height of the upper cylindrical section are D = 2.1 m and E = 2 m, respectively. In this simulation, the bottom of chamber was fixed because it helps the converter to reach the maximum efficiency. In addition, the assumption of fixed bottom chamber was applied to have a better convergence in the solution process.

3.3. Inlet and outlet valves

In order to select the valve type, three factors should be considered including software limitation for simulation, large diameter of outlet pipe, and valve compatibility to seawater. According to the research, Wafer Swing Check Valve could be a suitable choice for this valve, which this kind of valve is indicated in Fig. 2(c) schematically. According to the valve catalogue of the CLA-VAL company [34], this valve was made of Aluminium Bronze ASTM B148, Alloy 95200, so the density was assigned 7.64 gr/cm^3, and the size F and G sections were 0.8 m and 0.536 m, respectively. The properties of outlet valve were set the same as inlet valve in modelling. As shown in Fig. 2(c), a circle disk was designed as inlet and outlet valve, and this disk rotates in Y direction (pin) freely similar to Fig. 2(c).

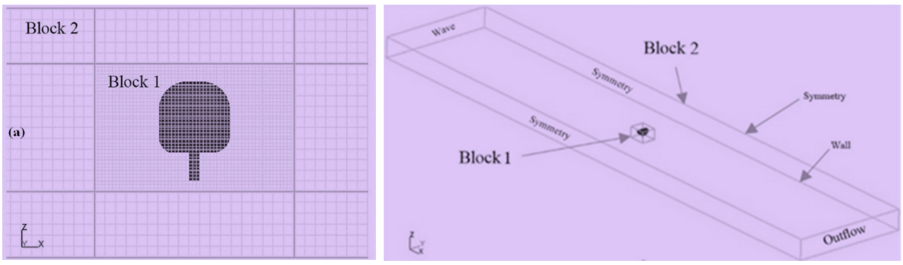


(a) (b) (c)

Fig. 2. Schematic view of (a) buoy; (b) chamber; (c) inlet/outlet valve (Wafer Swing Check Valve).

4. Validation

In order to verify the numerical results in *Flow*-3D, a point absorber named "WRASPA" was simulated exactly similar to the experimental model in reference [35] to compare the numerical and experimental data. As it can be seen in Fig. 3(a), not only were the structured meshes utilized for solution domain, but also two mesh blocks were generated with different sizes to improve the accuracy. In other words, the mesh Block 1 has small grids in which the point absorber was simulated at the middle and the mesh Block 2 has larger grids around the Block 1. In addition, the different boundary conditions for this simulation are completely shown in Fig. 3(b).



(a) (b)

Fig. 3. (a) Schematic view of meshing the wave tank and WRASPA; (b) Axis and dimensions including boundary conditions.

In this work, the setting parameters include the wave amplitude of 0.01 m, time period of 1 s, and water depth of 0.42 m. The mesh number is 963210 and its smallest grid (0.006 m) was generated to model the moving wave inside the tank. As shown in Fig. 4, the wave tank dimensions are 12.5 m long, 1.5 m wide and 0.45 m high. Furthermore, the RNG (k-ε) turbulence model was employed to solve the turbulent flow because it has acceptable accuracy for this case. The position of buoy (based on the angular movement in radian) for WRASPA is displayed in Fig. 4 which they are in reasonable agreement with each other and their differences can be almost acceptable except for the vicinity of the peaks.

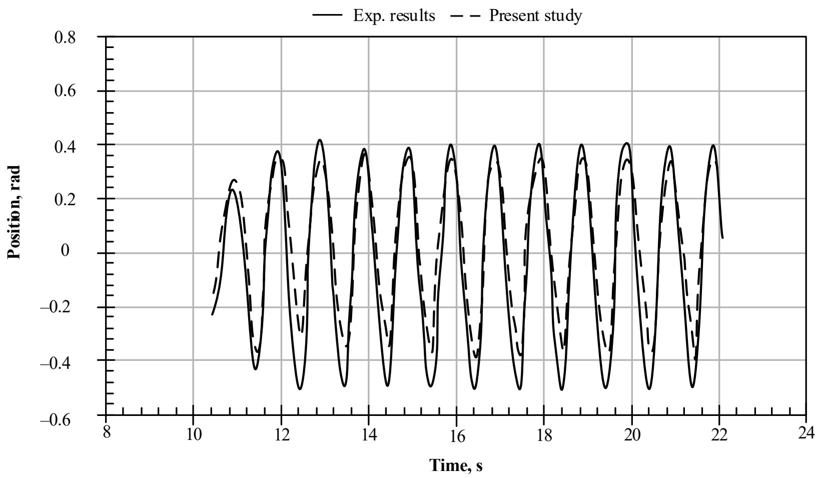


Fig. 4. Comparison of numerical and experimental results for angular rotation.

5. Boundary conditions and mesh blocks

In the present work, meshing the solution domain was extremely important because fluid and solid were moving simultaneously. According to the ability of meshing in this software, three mesh blocks were generated with structure type to improve the accuracy of calculations. As indicated in Fig. 5, X and Y coordinate axes were on the center of upper buoy and Z axis was in direction of ground gravity. In Fig. 5, the abbreviations of WV, S, O, and W stand for wave, symmetry, outflow, and wall conditions, respectively. In addition, the RNG (k-ε) turbulence model was utilized to model the turbulent flow while the wave was sinusoidal.

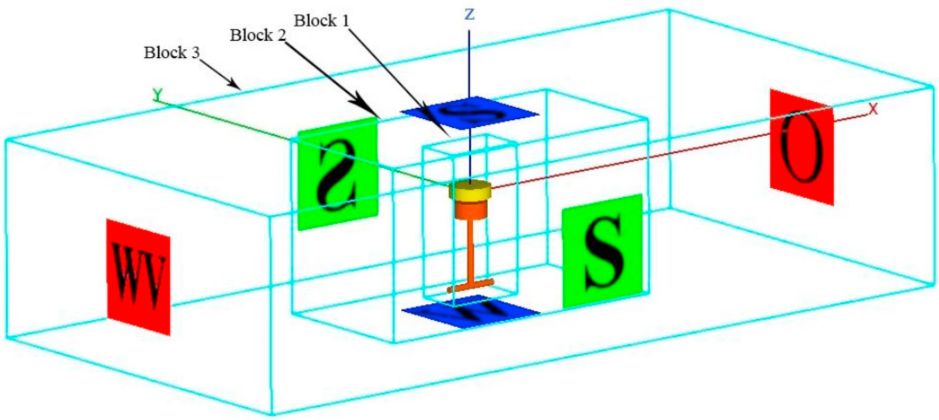


Fig. 5. Boundary conditions and mesh blocks.

6. Results and discussion

In Fig. 6, hydrostatic pressure contour was depictured in three dimensions for wave tank. As it can be seen in this figure, the wave generation starts from X_{min} moving toward the X_{max} after passing the Searaser. As shown, hydrostatic pressure increases linearly in the wave tank because the water depth linearly grows up.

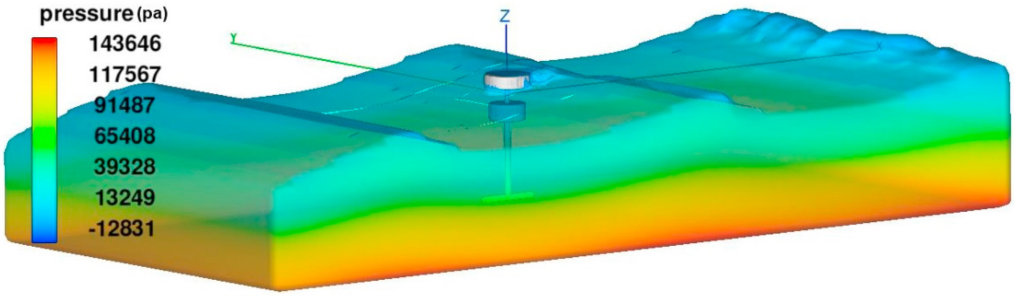


Fig. 6. Hydrostatic pressure contour in the wave tank.

In Fig. 7, velocity contour is indicated when the water is drawn by inlet valve. By reaching the wave near the upper buoy, the buoy moves upward and causes the water to be drawn into the inlet valve. Afterwards, the buoy goes down when the wave passes the Searaser and the buoy weight causes the water inside the duct to be extracted from outlet valve.

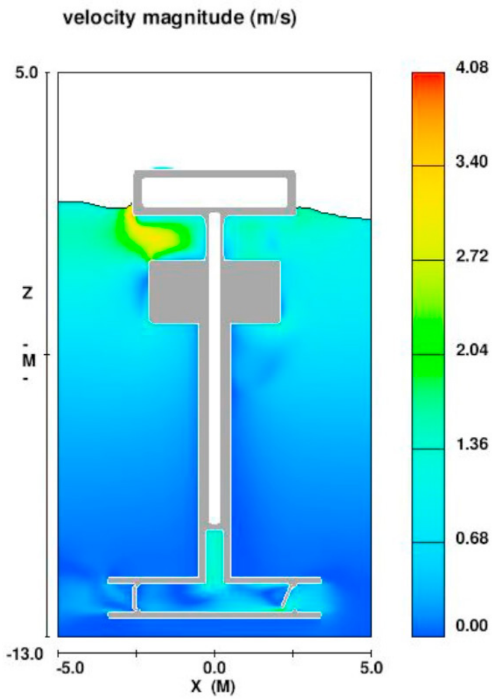


Fig. 7. Velocity contour in the suction occasion time 21 s.

7. Conclusions

Nowadays, OWECs have been found one of the best appropriate systems to harvest the wave energy. Hence, the commercial software (*Flow*-3D) was employed to simulate a novel wave energy converter. A new wave energy converter named "Searaser" was introduced as a patent in 2013. This research investigates the capability of *Flow*-3D commercial software in numerical simulation of this device. For validation of results, experimental and numerical results were compared for motion of buoy, and they showed a good agreement. In this simulation, the upper buoy of the converter was designed to move upward by the ocean waves generated in a three-dimensional wave tank including water. Structured mesh was generated to improve the run time and accuracy of simulation. To solve motion equations of interaction between solid and fluid section, Reynolds Averaged Navier-Stokes equations were coupled with volume of fluid (VOF) model to generate three-dimensional numerical linear propagating waves. Hydrostatic pressure and velocity contour were shown with motion of buoy while water wave passes the buoy. Although mesh generation of solid and fluid domains is different in this software for sake of simplicities, results reveal the capability of *Flow*-3D software for modelling the fluid structure interaction (FSI) problems including wave motions. Future works are required to compute the power generation of this energy convertor with numerical simulation.

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