Thesis for the Degree of Master of Fisheries Science

Deformation of Nylon Net and Copper Alloy Net in Fish Cage Models Subjected to Current Velocity

by

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KOICA-PKNU International Graduate Program of Fisheries Science

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나일론 망지와 황동망으로 제작된 모형 가두리의 유속에 따른 변형

Advisor: Prof. Chun-Woo LEE

by

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Abstract

Focus in netting material is important in aquaculture industry, which is preventing fish from escape and keeps it safe from predation. In this paper our study mainly focused on the effect of using a variable netting material at cage deformation and tension of mooring system at the same current velocity. The deformation and tension of mooring line was analyzed using two small model fish floating type cages in a flume tank experiment, model A was a Nylon netting material with additional weight sinkers and model B was a copper alloy net cage without additional weight sinkers. However, the two cage models have the same weight in water while any other components and dimensions of the two cage models are the same. In this experiment the deformation of those two models A and B was investigated when exposed to current velocities 0.1, 0.2, 0.3, 0.4, 0.5 and 0.6 m/s in a flume tank. The responses of the models by the action of water current were measured using digital camera and load cell at mooring line. Additionally, a digitizer was used to determine the displacement of selected points on netting system. The results from this experiment are presented and discussed to explain the dependency between current force and cage structure. Findings show that at 0.6m/s current velocity i) the volume reduction ratio of copper net is lower than nylon net. Consequently, the drag coefficient is lower when using copper net; ii) tension at mooring system is higher at copper net cage, which corresponds to higher drag force; and iii) the copper net maximize the difference between front wall and rear wall deflection angle which it is directly related with shielding effect.

Finally the copper alloy net has a promise in improving biofouling resistance and that leads to reduction in net maintenance for the system.

1. Introduction

Global aquaculture industry has been developed significantly during the past few years. Many factors have made this developing imaginable. One is development of aquaculture engineering, for example the improvements in technology which allowing reducing the consumption of freshwater such as using Biofloc technology in aquaculture, and development of recycling systems. Another is the development of offshore cages sites which can be used today with good results (Lekang, 2007). Aquaculture cage system are normally placed in bays or protected onshore waters (Lee et al., 2008), that was because of easy management, low construction cost and to preserve from open ocean factors. Inshore water is not much suitable sites for cages because of self contamination, bad water quality, and low oxygen level. It is now important to depend on water current to maintaining the water quality in fish farming areas. When water flows, the water pollution problems are minimized through effective dispersion of waste products (Zhan et al., 2006). For these reasons, fish farms are recently located offshore, where higher growth rate of fish are expected, because of better water quality. But moving to offshore areas is a big challenge, the area with high energy oceanic factors cause a lot of negative effects such as larger deformation and volume reduction ratio by strong current and high waves. Maintaining the original volume of the fish cage is most important for safe aquaculture, because large deformation lead to stress for fish, and accelerate material fatigue of cage system. Huang et al. (2008) conclude that farming sites should not be situated in areas where the current speed more than 1 m/s. So, the purpose of this study is to understand water current effect of cage chamber deformation and tension on mooring system while using two kinds of netting materials Nylon and Copper.

New technological methods are developed by researchers to design reliable fish cage system that can tolerant strong oceanic factors. Consequently, it is requires a deep knowledge of net cage performance by the action of current and waves. Dynamic simulation is the best, cheap, accrues and less time method used to understand of the hydrodynamic forces affecting on nets in different operating conditions. Lee et al. (2008) conclude that the simulation technique and mathematical calculation methods can be used to evaluate and estimate the safety of a large-scale moored cage structure exposed to environmental forces. Lee et al. (2005) proposed a mathematical model using the mass-spring model to simulate the behavior of fishing gear systems.

Computer-aided behaviour analysis for fish cages systems have been conducted by many researchers. Tsukrov et al. (2003) developed a consistent net element method that has been used in the numerical modeling of open ocean aquaculture systems. Huang et al. (2008) studied the influence of water depth on cage systems using field experiment. In their conclusion, a cage installed in shallower water site had higher mooring tension and greater volume deformation than the cage installed in a deep water. Lee et al. (2008) presented a mathematical model and described a simulation method besides using a physical model for analyzing the performance of circular and square fish net cages. Numerically the cage system was modelled on the mass-spring model, nettings and ropes are regarded as flexible structures and the floating collar as an elastic structure.

Current and waves are two of the environmental factors that affect on net cage, since the purpose of fish cage is breeding fish. Consequently, it affect on fish inside cage. Despite the good effect of current for maintain a suitable water quality for fish such as replenishment of the oxygen, but currents impose an additional dynamic loading to cage system. When the cage was exposed to the current, a great change of cage structure has occurred and the tension on the upper part of the cage greatly increased (Lee et al., 2008). The combined effect of current and waves is greater than wave effect alone, consequently the net cage changes its shape by deformation and deflection. The extent of the change depends on the flow velocity, the original shape and construction of the net cage, the netting type which the net cage is made of, the amount and placement of bottom weights (Fredheim, 2005).

Lader et al. (2008) suggest that development of an early warning system for fish farm operators to detect significant deformations in nets. Huang et al. (2008) illustrate the combination effects of waves and currents on the structure of a net-cage system, and describe this combination effect that when waves travel along with currents, the wave length becomes longer than the wave and the wave height becomes smaller. For waves traveling against currents, the wave length becomes shorter and the wave height increases. This phenomenon is more obvious in shallow water regions than in deep-water regions. Klebert et al. (2013) reviewed the interaction between current flow and net panels, net gages, fish schools and biofouling.

Fish cage systems consist of netting, mooring lines, a floating collar, floats, and sinkers. Netting and ropes are the basic components of marine cage structure (Lee et al., 2008). The main focus for scientists and engineers in structural designing of fish cages is netting materials and mooring system. Netting meshes shape can be diamond or square shape, and these are classified as knotted and knotless netting. The main purpose of netting in fish cages is to prevent the fish from escape, secure from predators, while permitting sufficient water exchange to maintain a good water quality condition. Netting materials are commonly Polyethylene, Polyamide, and copper. The use of copper alloy netting in marine aquaculture is now increase and shows a lower drag coefficient (Tsukrov et al., 2011), besides it shows a high preventing fish from escape and loss due to predation (Jensen et al., 2010), also copper alloy net has a promise in improving biofouling resistance and that leads to reduction in net maintenance for the system (González et al., 2013). The mooring line is used to fasten the cage system at specific location, and prevent it from drifting away due to environmental factors. Physical properties of a mooring system depend on type and structural components of fish cage. Material properties such as durability and strength are main factors that should be considered. Buoys are floating system act as a cushion to absorb the hydrodynamic impact forces. It also used as boundary markers to denote the size of fish farming

(Huang et al., 2007). Floating collar is the tube which attached on the top part of netting. It was usually made of PVC (polyvinyl chloride) pipes, but HDPE (high density polyethylene) pipes is now the most popular used in fish cage farms, it can easily float on the water surface because it has a lower density than water.

The objective of this study is to investigate dynamic response of two kinds of physical models of circular net cages with different netting material and sinking system under water when they subjected to current in flume tank. In this paper, our study focused on netting material. So, two cage models have been designed for this study, model A the netting material is Nylon with bottom weight sinkers and model B the netting material is Copper alloy without sinker. Nevertheless, the both cages have the same weight in water. In model B we depend on the specific gravity of copper net itself which is 8.9 to be sinker, so no additional sinkers are attached to the system. Dimensions and other materials used for the both cages structure components are the same including floating collar and mooring system. Tension of the mooring system and deformation of cages where investigated through this experiment subjected different current velocity at a flume tank.

2. Materials and Methods

2.1 Physical cage model

In this study two models of fish cage are used to represent two diverse designs. Netting material is the variable factor in the two models, model A is for circular net cage with Nylon netting material and model B is circular net cage with Copper alloy netting material. The physical models are composed basic structural components such as floating collar, sinkers and mooring lines. It should be noted that, the copper alloy net cage is not attached by weight sinkers, that's because of the high specific gravity of copper which it is 8.9, and we can depend on the copper net itself to be a sinking method, while model A cage attached sinker is 4 kg. So, the both cages have the same under water weight.

Netting material for model A is made of polyamide (Nylon) with density 1.14 g/cm³, and it is rectangular knotless type with mesh bar 19 mm and twine diameter 1mm. Model B net is made of copper alloy with density 8.94 g/cm³, and it is chain-link diamond type with mesh bar 11 mm and twine diameter 1 mm. Bottom sinkers are used only for nylon net cage, 8 cylindrical shaped stainless weights were used as sinking system with

500gm for each and total sinking force 4 kg/f (Table 1). Bottom panel collar material is high density plastic (HD Plastic) with a 1000 mm diameter, 5mm Thickness and 2.03 g/cm³ density. For the both cages, the main use of bottom panel is to maintain the cylindrical shape of the cage.

The floating collar is made of high density polyethylene (HDPE), the floating collar is Octagonal-shaped with 76 mm pipe thickness and the length of each rib is 500 mm. Two types of mooring system are arranged for each cage (Fig. 1), both of these types are single pointed mooring system. Mooring type 1, a single rope with 600 mm length was connected to the load cell from one end at the same level of water surface and joined with other two ropes with 1130 mm length each, then those two ropes oriented into two different directions met with floating collar at two connection points. Finally, the connecting point of these three ropes is located 600 mm from the floating collar and perpendicular to the centre of rib. Mooring type 2, a single rope with 600 mm length was connected to the load cell from one

Table 1. Specifications of the physical cage models.

Item	Specification	
	Nylon Cage	Copper Cage
Floating collar		
Material	HDPE	HDPE
Density (g/cc)	0.953	0.953
Pipe diameter (mm)	76	76
Shape	8 ribs (octagon)	8 ribs (octagon)
Rib length (mm)	500	500
Netting		
Material	Nylon	Copper alloy
Density (g/cm³)	1.14	8.94
Net depth (mm)	780	780
Mesh type	Rectangular knotless	Chain-link diamond
Mesh bar (mm)	19	11
Mesh size (mm)	38	16
Twine diameter (mm)	1	1
Bottom weights		
Material	Stainless steel	-
Unit mass (g/piece)	500	-
Number of pieces	8	-
Total mass (g)	4000	-
Mooring line		
Material	Nylon	Nylon
Diameter (mm)	3	3
Bottom panel collar		
Material	HD Plastic	HD Plastic
Diameter (mm)	1000	1000
Thickness (mm)	5	5
Density (g/cm³)	2.03	2.03

end at the same level of water surface and joined with other two ropes with 970 mm length each, then those two ropes oriented into two different directions met with floating collar at two connection points. Finally, the connecting point of these three ropes is located 600 mm from the floating collar and perpendicular to the point of connecting of two ribs.

2.2 Design plans for physical cage (model A)

The structural design for cage model A with weight sinkers is depicted in Fig. 2. The nets of this model were formed to have top opened cylindrical shape with diameter 1000 mm and 780 mm depth. The net panel is tied from top at floating collar and from bottom at bottom collar. The bottom weight sinkers attached at the bottom collar.

2.3 Design plans for physical cage (model B).

The structural design for cage model B is depicted in Fig. 3. The nets of this model are chain-link diamond type and it was formed to have top opened cylindrical shape with diameter 1000 mm and 780 mm depth.

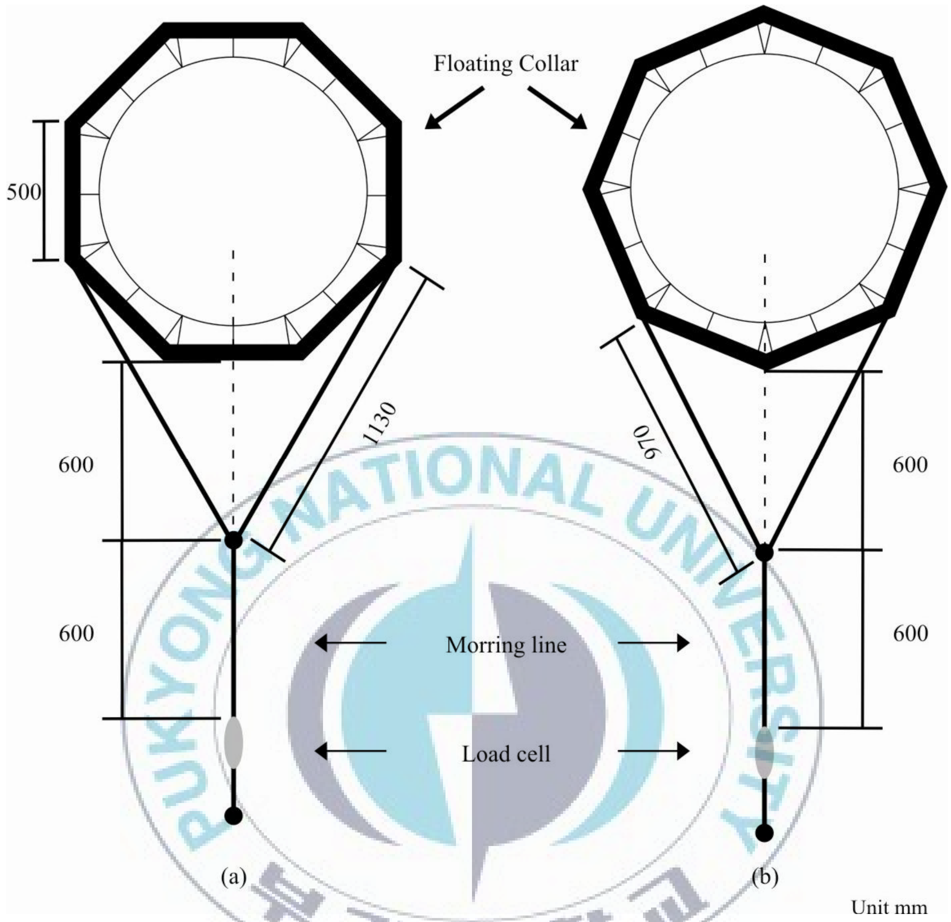


Fig. 1. Top view shows the mooring line types and dimensions, floating collar shape and load cell position; (a) mooring type 1, (b) mooring type 2.

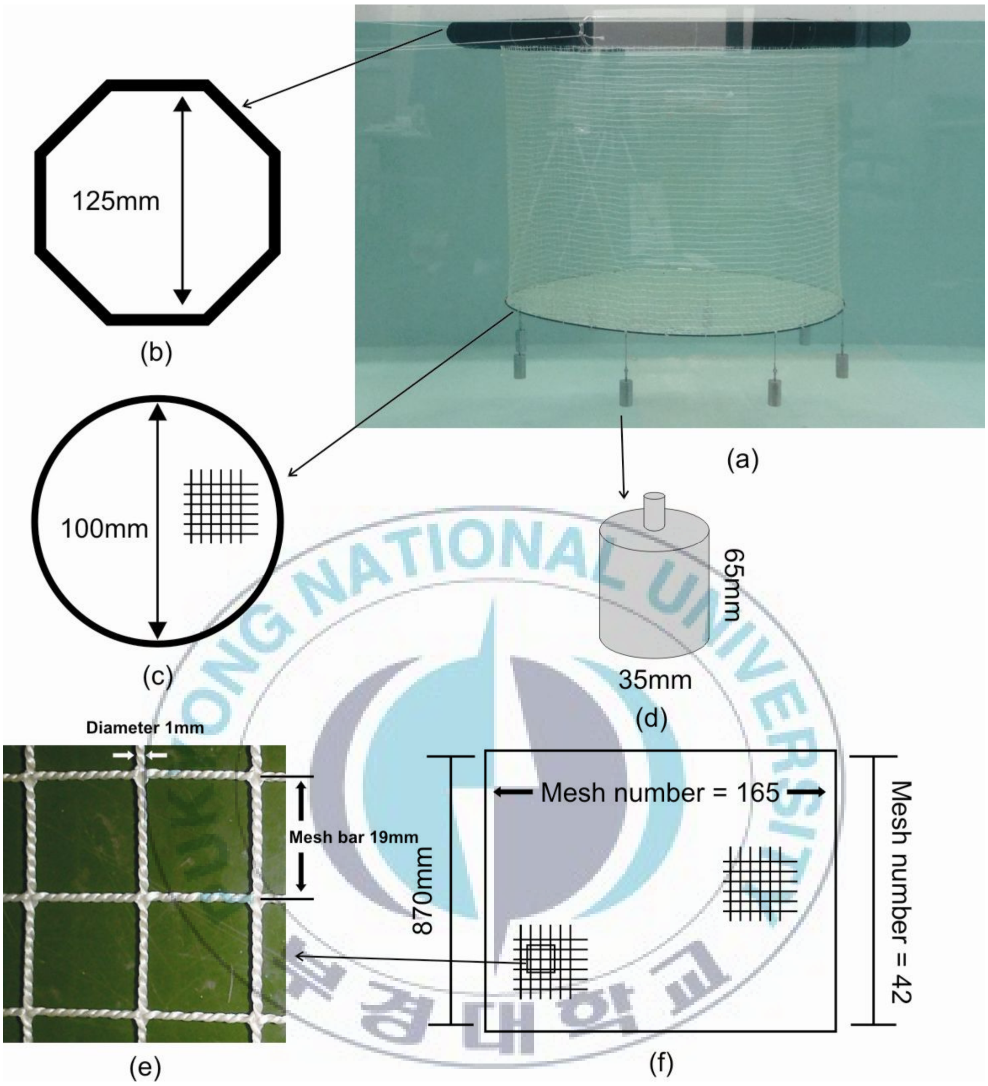


Fig.2. Design plane for the nylon net cage specifications; (a) Model cage A, (b) floating collar, (c) bottom panel collar (d) weight sinker height and diameter, (e) mesh bar length and twine diameter, (f) total mesh numbers at un-folded net.

2.4 Experimental setup for flume tank.

The experiment was conducted at Pukyong National University (PKNU), Busan, South Korea. A flume tank was used in this study to experiment the effect of water current at two cage models. 3D flume tank with dimensions of 10.20 m x 3.20 m x 2.50 m (Length x Height x Width) equipped with a uniform current producing system (Fig.4.). It is flowing along horizontal direction using circulating water channel system. Current producing capability ranges from current speed 0.1 m/s to 1.2 m/s. cages were dipped into and positioned in flume tank with a single point mooring system, a single load cell to measure a tension was fixed at the beginning of mooring rope which is directed toward incoming water current.

Digitizer was used to find positions of selected points at a two dimensional coordinate system. Moreover, a digital camera was placed in front of flume tank observation window to snap a shot of cage deformation at different current velocities. The load cell is connected with mooring line from one side and the other side connected with under water tension meter system which is connected with a computer to analyze and record the tension force.

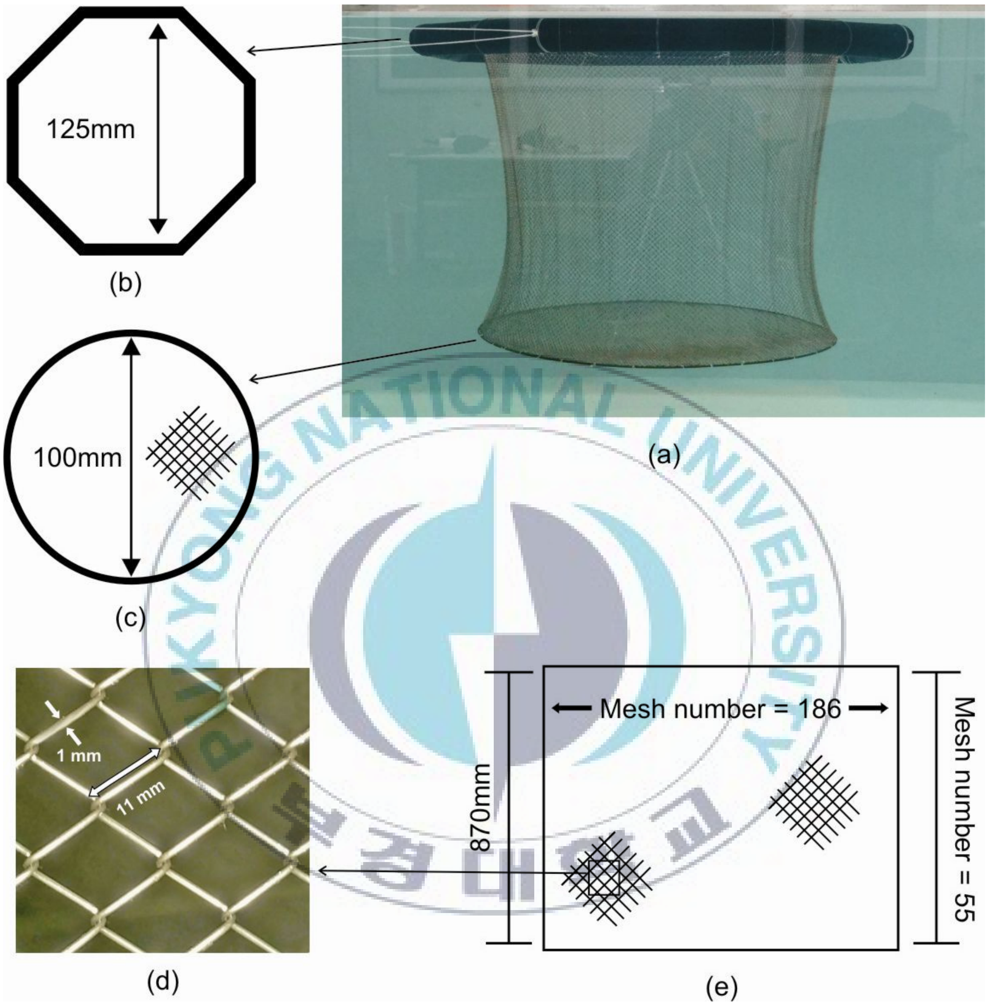


Fig.3. Design plane for the copper net cage specifications, (a) Model cage B, (b) Floating collar, (c) bottom panel collar, (d) mesh bar length and twine diameter, (e) total mesh numbers at un-folded net.

Seven colored markers were put at selected positions around the cage to detect the displacement and deformation of the cage models along x-z coordinate plane (Fig.5). Models were exposed to different current velocity along horizontal x-axis direction, from 0.1 m/s to 0.6 m/s at 0.1 m/s interval. At each current velocity, model cages are started to move in x-z coordinate plane, and after some time, they reached at a stable state. Then, 2D displacements of the selected points on x-z coordinate are detected by digitizer (Fig.5).

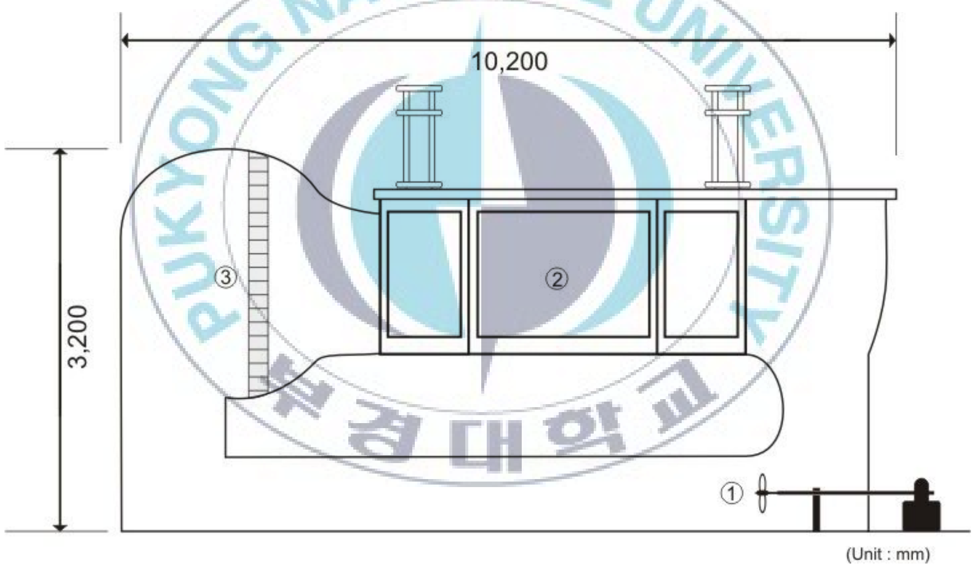


Fig. 4. Schematic drawing of the flume tank,

1-Impeller 2- Observation window

3-Honeycomb

Volume of the cage was assumed to be proportional to the cross-sectional area (Lader et al., 2008). Consequently, the volume reduction coefficient was also assumed as the ratio between the instantaneous cross sectional area subjected to the current velocities and the static condition area. On this approach, structural deformation regarding to the volume was analyzed and compared for each models in flume tank test.

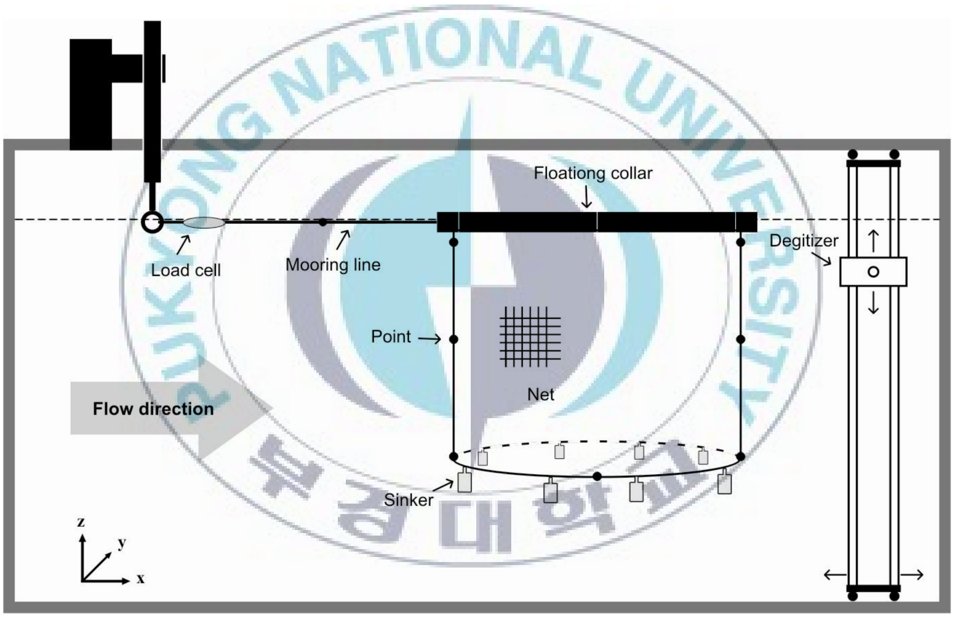


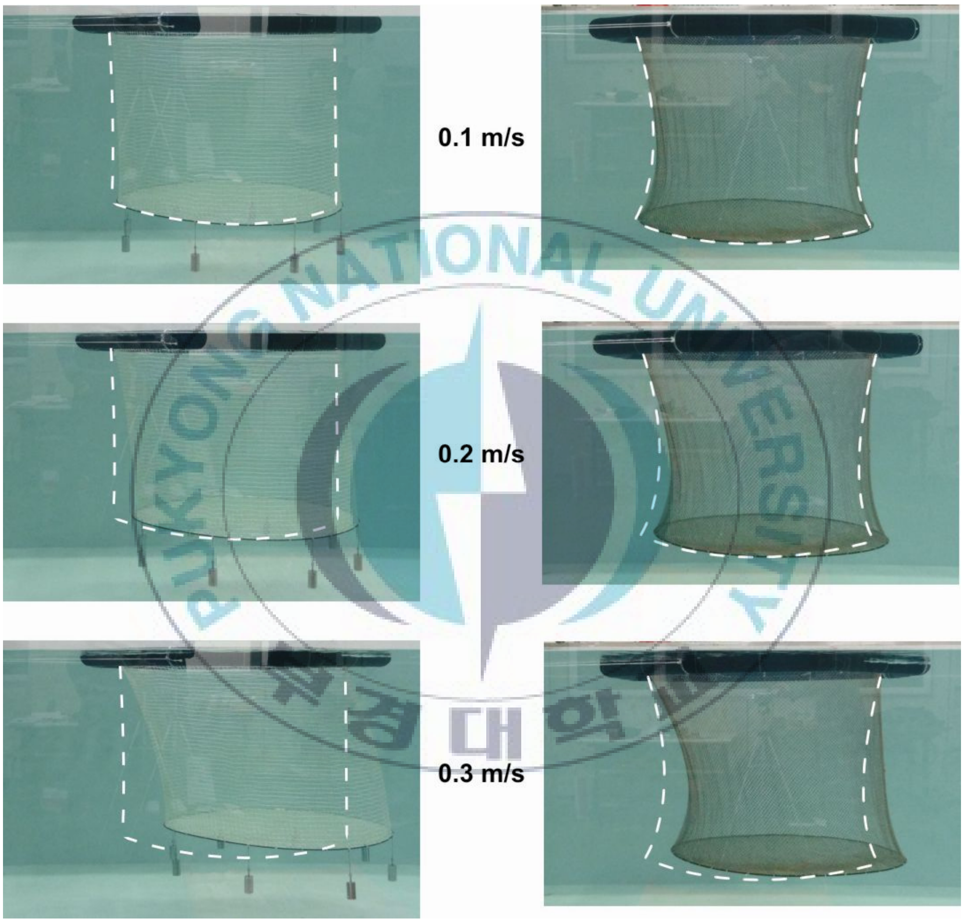
Fig. 5. Side view of observation window at flume tank, it shows the experimental arrangement of cage (model A), and the position of marked points.

3. Results

3.1 Deformation of cage models

When model cages subjected to current action, they will response by gradual reduction of their cross-sectional area and their volume as well. As the current speed increased, the hydrodynamic force on the model cage system increased and the deformation value also increased. Using a digital camera installed in the front of the observation window, six snapshots were taken for each cage at each current velocity from 0.1 m/s to 0.6 m/s at 0.1 m/s interval to investigate the deference in shape deformation (Fig. 6). The white outline appears in Fig. 6 indicates to the original shape of the cage at 0 m/s current velocity. From this pictures we can notice that at current velocity 0.1 m/s, 0.2 m/s and 0.3 m/s there is a slightly deformation in both cages, but when increasing the current velocity to 0.4 m/s, 0.5 m/s, and 0.6 m/s the cage model A shape deformation is higher than cage model B. Using mooring type 1 and 2 are not much difference in the cage deformation and tension on mooring system.

(Model A) (Model B)



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(Model A) (Model B)

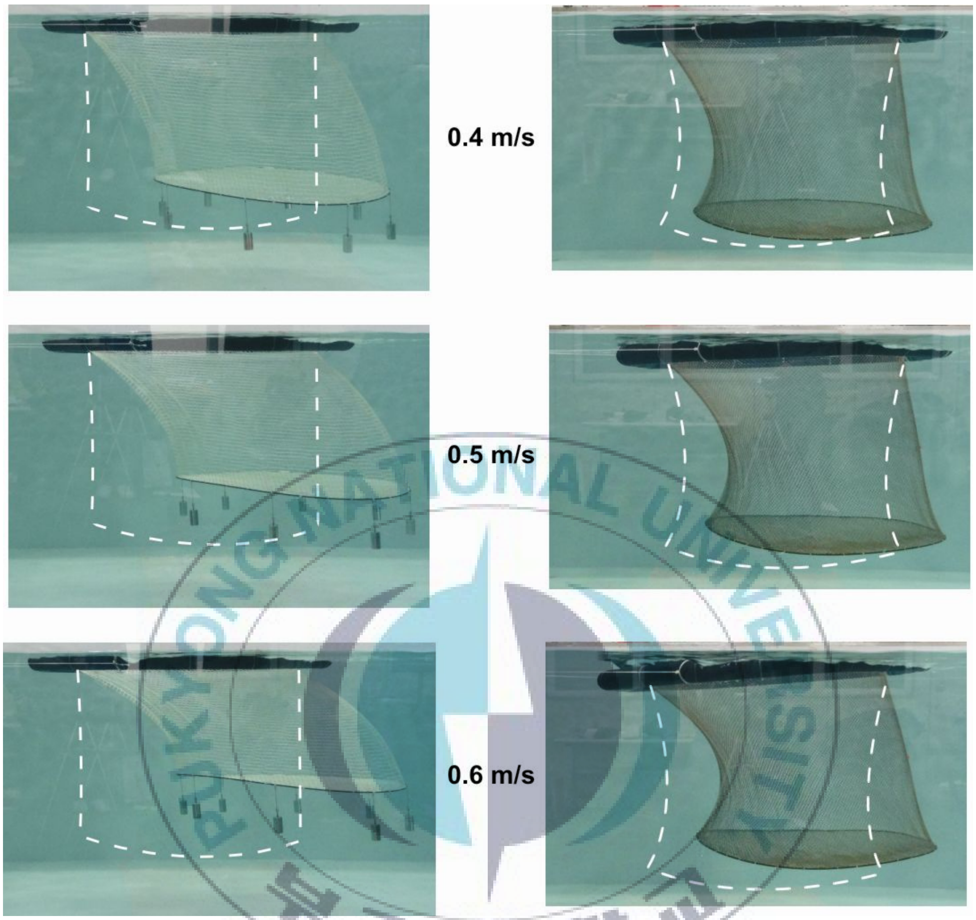
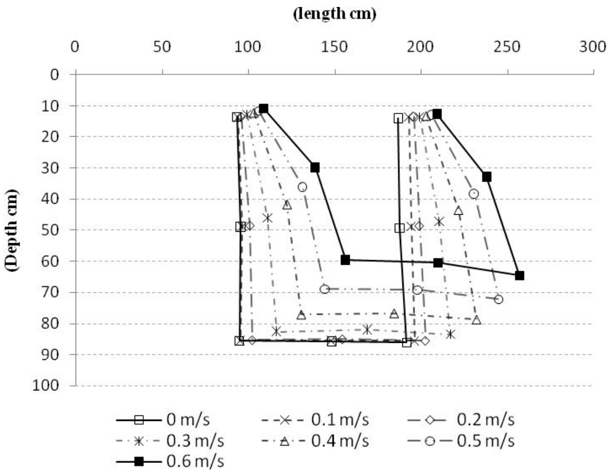


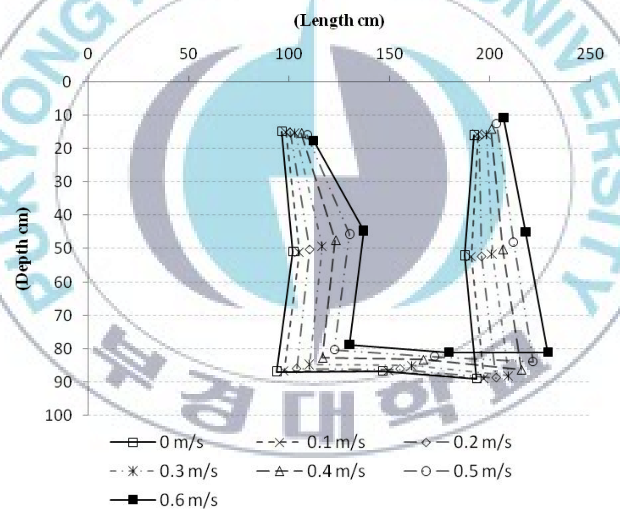
Fig. 6. Comparison of shape deformation of model cages using mooring type-1 at different current velocity. The white broken line indicates to the original shape of the cage at 0 m/s current velocity.

3.2 Volume reduction of cage models

In this study, volume reduction is used to describe volume deformation of cage models under different current velocity. On the basis of the assumption that cross sectional area is proportional to volume of the cage models, the volume reduction of the cage was investigated. The volume reduction coefficient is the ratio of cross sectional area of cage at specific velocity to cross sectional area of cage at zero current velocity. The data obtained from digitizer helps to investigate the volume reduction coefficient. The volume reduction in cage models is depicted in Fig. 7. When the current velocity increases the volume reduction coefficient increases too.



(a)



(b)

Fig. 7. Comparison of shape volume reduction; (a) model cage A, (b) model cage B.

Both models responded to the action of the current by decreasing volume, but the reduction in volume was greater at model A than model B at current velocity 0.4 m/s, 0.5 m/s and 0.6 m/s. while, at lower current velocity 0.1 m/s, 0.2 m/s and 0.3 m/s there was a slightly difference in volume reduction coefficient. The relation between current velocity and volume reduction coefficient is depicted in Fig. 8.

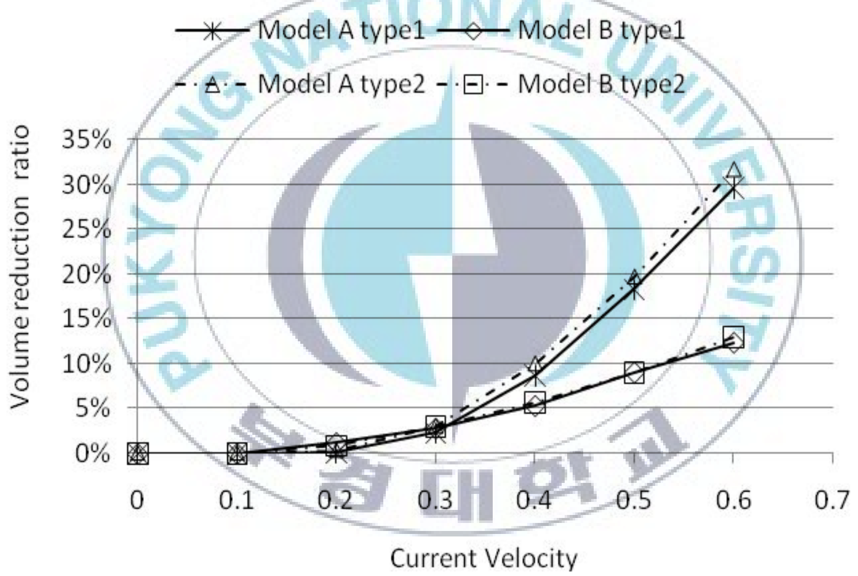


Fig. 8. Relation between current velocity and volume reduction coefficient at mooring type 1 and type 2.

3.3 Angle of deflection of net

Two dimensional displacements of selected points on the x-z coordinate illustrate a deformation in shape of the cross sectional area of cage by the action of current (Fig. 7). The sides of cages net can be viewed as containing front wall, back wall and bottom panel. Front wall is directed to the incoming current and it responds differently from the back wall of the net when subjected to water current. Angle of deflection is angle formed either between the corresponding front sides or back sides of netting when it is in deformed and undeformed state (Fig. 9).

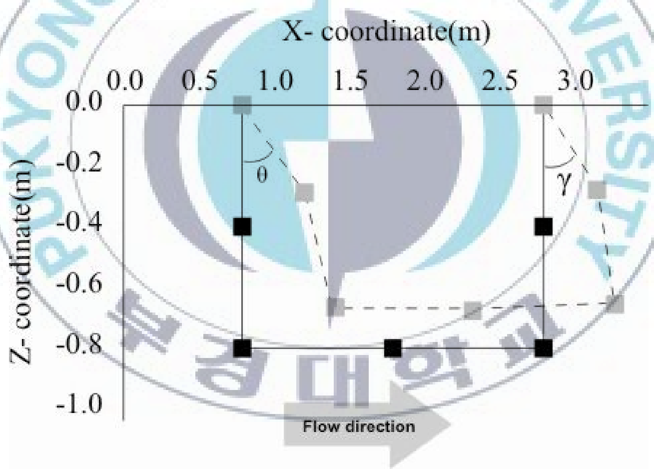


Fig. 9. Angle of deflection of walls of netting; front wall deflection (θ), back wall deflection (γ); black colored figure indicates original state of net and gray colored indicates the deflection of net.

Angle determination based only on the first two points of front wall and last two points of the back wall. Consequently, the bottom panel contribution of the cage total space reduction is little, because it would in general experience a high degree of shadow effects as this part would be close to horizontal (Moe et al., 2010). The cage models at 0m/s current velocity exhibit a deflection angle as a result of structure and different net material especially at model B. So, the angle of deflection which is shown in next results was calculated as the increment of the original angle at 0m/s current velocity.

3.3.1 Angle of deflection of net at mooring type 1 and type 2

There are lose of energy inside the cage net, which mean that the back wall of the net subjected to smaller water velocity (Zhan et al., 2006), this is sometimes called shielding effect. Consequently, the back wall angle of deflection is smaller than front wall angle of deflection (Table 2 and 3).

Table 2. Increment of the angle of deflection for cage models due to current velocity at mooring type 1.

velocity (m/s)	Angle increment (degree)			
	Model A		Model B	
	θ	γ	θ	γ
0	0	0	0	0
0.1	0.96	0.80	1.1	1.9
0.2	4.96	4.47	6.5	8.8
0.3	16.12	17.18	12.6	11.6
0.4	29.23	30.18	20.0	16.5
0.5	41.24	42.21	26.4	20.8
0.6	52.40	52.02	34.3	25.0

Table 3. Increment of the angle of deflection for cage models due to current velocity at mooring type 2.

velocity (m/s)	Angle increment (degree)			
	Model A		Model B	
	θ	γ	θ	γ
0	0	0	0	0
0.1	1.12	1.28	3.1	2.4
0.2	4.33	5.11	6.9	9.6
0.3	16.71	16.24	12.8	14.1
0.4	30.64	29.84	20.0	19.7
0.5	43.65	41.15	26.2	24.5
0.6	57.59	51.82	35.2	29.1

3.4 Tension response by the action of current

As the water flow act on cage systems, the cages dragged horizontally at the x coordinate while the bottom panel dragged upward at z coordinate. According to Morrison equation, current force is proportional to the square of the current speed. So, the increase in current velocity will result a high current force. Consequently, the reaction force by the total cage system will be high which mean a progressive increment of tension loads will accrue. However, the magnitude of response differs in each cage model.

Tension loads on mooring systems of model A and Model B is almost the same at current velocity 0.1 m/s, 0.2 m/s and 0.3 m/s, but at current velocity 0.4 m/s, 0.5 m/s and 0.6 m/s model B exhibit a higher tension than model A (Fig. 10). At mooring type 2, the tension loads at mooring system are little bit smaller than mooring type 1. Tension as a function of current velocity forecast that reaction force by mooring system to be proportional to current velocity.

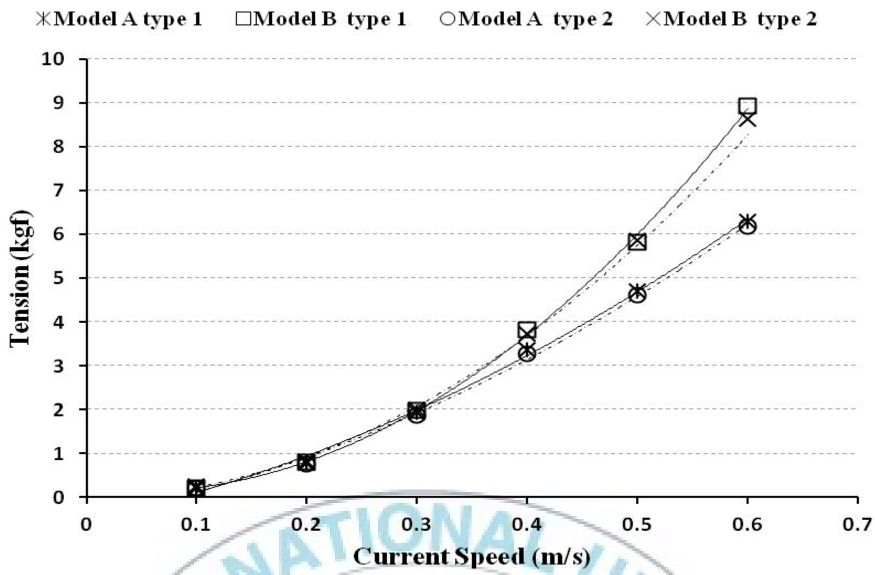


Fig. 10. Relation between tension force of mooring system and current speed at mooring type 1 and 2.

3.5 Deformation of the cages as a function of mooring tension

Cage volume reduction ratio will decreased with the increase of current velocity or current force action. Fig. 11 shows that tension and deformation of the cage are more likely to be dependent to each other. As the tension on the mooring system increase, the volume reduction ratio also increases in both mooring types 1 and 2. However, at equal tension force, cage model A had a higher volume reduction ratio than model B.

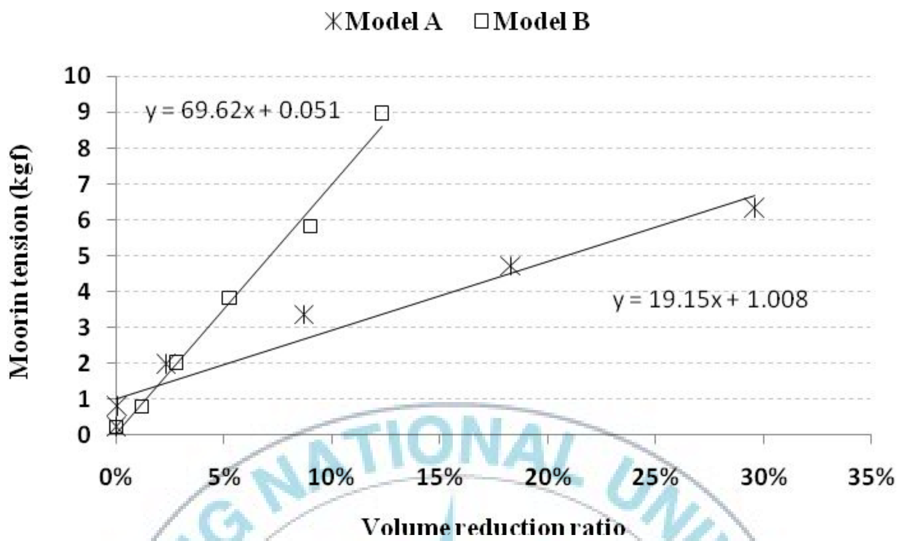


Fig. 11. Deformation of the cage models as the function of the mooring tension.

4. Discussion

In this study, the netting material which it is the basic and biggest components of cage construction was the main factor on the experiment. A Nylon and Copper Alloy nets were used to make two small-scale fish cages. It was important to investigate the effect of using different netting material on deformation of the fish cages and the tension of mooring system.

Our findings confirm that using a copper alloy net in fish cage construction has a significant impact on deformation of the fish cage and the tension of mooring system. Otherwise, using a different mooring type on this experiment has no significant impact on deformation or tension. Digital camera results (Fig. 6) explain that both cage models responded to action of current force by gradual reduction of their volume or cross sectional area. Model cage B possessed a lower volume reduction coefficient than model cage A in current velocities 0.4 m/s, 0.5 m/s, and 0.6 m/s. Drag and lift forces are increased with the increase of current velocity, but the volume decreased (Moe et al., 2010). So, in this case copper net possessed lower drag coefficient and less volume reduction. Cha et al. (2013) concluded that the coefficient of the copper alloy net were lower than fabric net at the attack angle over 30° and this may due to different structure between nets.

The difference of volume reduction ratio between the two models, specifically at current velocity 0.4m/s, 0.5m/s and 0.6m/s were 8.7%, 18.3%, and 29.6% respectively for nylon net cage and 5.3%, 9%, and 12.3% respectively for copper net cage (Fig. 8). This further explains that as the current speed become higher, the difference in volume deformation between models will be significant. Lader and Enerhaug (2005) conducted an experiment on a nylon net cage with different bottom weights, they illustrated that with lower velocity the deformation was lower than 5%, but for higher velocity the deformation becomes larger and the capability to deform also increase with the increase of current speed. The deflection of the net parts is another indicator for the cage volume reduction because it had different impacts on the total space of the cage. Front wall inward deflection has a volume reduction effect while outward deflection of rear wall has an increasing effect. The water velocity reduces when passes the front portion of the net with 20% from the incoming current velocity (Lader and Enerhaug, 2005). Consequently, the force action on the rear portion of the cylinder net is lower than the front portion (Zhan et al., 2006). Results from table 2 showing that in model cage (A) there is no different between front wall and back wall angle but in model (B) there is a different between front wall and back wall angle which mean that the current force is decreased in model (B) but for model (A) the current force is almost same. The relationship between current velocity and forces in the flexible net structure are complex because the force and deformation depend on each other, the force coefficient depend on solidity and angle of attack while a different areas in the net structure have a different angle of attack (Lader and Enerhaug, 2005). That's explains that when using a different mooring type all the angle of attack of the net structure is changed. Consequently, the forces of current may be change too and we got different results (table 3).

Our result shows that the tension at mooring system is higher for model B than model A when exposed to current velocities 0.4 m/s, 0.5 m/s and 0.6 m/s, and with using mooring type 1 or 2 (Fig. 10). Tension forces measured can be considered as the sum of total forces of the drag and lift forces (Moe et al., 2010). A slight inclination of floating collar of model B at current velocity 0.6 m/s result in an increase in projected area of collar. This might lead to increases of drag force. That's may explained the higher tension of mooring line at model B. Drag and left forces are a function of current speed and projected area. With an increase either one of the two factors alternatively or together, it will increase drag and lift forces. So, as the drag force increase due to increase of current speed, the cage will become more deformed to minimize its projected area as responsive mechanism. In the case of model B the using of copper net help to hold the cage structure which means that the projected area will be bigger than modal A. So, the drag force will increase due to current increase and bigger projected area, finely this will produce higher tension on mooring system of model B.

Biofouling is the accumulation of microorganisms, plants, algae, or protozoa on underwater equipment, pipes, and surfaces, nets. The natural and organic contents of feed Remnants, fish faecal production encourage the growth of algae at netting materials. So, the water around the fish cage is good environment four fouling. Net cleaning increases the cost of industry, Hodson and Burke (1994) in Australia, Atlantic Salmon industry, the nets must be removed for cleaning every 5-8 days during summer, this operation sometimes cause net damage and loss of stock. Hodson et al. (1997) presented a design of mechanical brush for a situ cleaner for cages net. Drag coefficient is influenced by net biofouling, Swift et al. (2006) calculated the drag force acting on clean nets and biofouled nets to understand the effect of biofouling on drag force at the same current velocity, the drag coefficient of biofouled nets is three times higher than clean nets. Copper and its alloys have a special fouling resistance, copper alloy with more than 70% copper is sufficiently toxic to marine fouling organisms (Huguenin and Ansuini, 1975). However, the environmental performance and effects of copper alloy is not simple matter, because of the corrosion rate of copper is very low and it is change over time and it depends on water flow, composition, and temperature. Copper's biofouling resistance is achieved by the slow corrosion of copper ions from the surface of the copper alloy materials.

5. Conclusion

In this study, the effects of current velocity on cage structure were studied with two cage models using a different netting material. Model (A) is a nylon net cage with additional weight sinkers and model (B) is a copper alloy net cage without sinker. However, the both cages have the same weight under water.

As a current velocity increases, the deformation of cage structure and tension on mooring system increases too. However, the loss of cross sectional area or cage volume of model A were higher than model B. Also for model B, the increment of angle of deflection of front wall of net which is directly exposed to current flow was higher than rear wall at current velocity 0.6 m/s. Here, the inward deflection of front wall has volume reduction effect but the outward deflection of rear has opposite effect. Consequently, the volume reduction is higher at model A because of higher deflection angle and this might be attributed to different netting materials which mean different physical characteristics.

Finely, the copper net showed good results to withstand current effects through lower volume reduction but with a higher mooring tension, so a developed mooring system is required while using copper net cages, also a reset of biofouling is one of the advantages of copper alloy nets because the fouling in aquaculture is a massive problem.

Future studies are required to understand more about copper net cage behaviour under water and the combined current-wave effect comparing with mathematical model using a dynamic simulation.

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