SOLUTIONS FOR SUSTAINABLE MARINE FISH FARMING

By Chien Ming Wang and Yunil Chu

Conventional nearshore open-net pen systems for marine fish farming are increasingly scrutinised due to their environmental impacts and elevated fish mortality rates. In response, two innovative solutions have emerged to enhance the sustainability of marine aquaculture: floating closed containment systems (for nearshore fish farming) and offshore fish farming. This article reviews the recent advancements in these two solutions and discusses their benefits and challenges.

Credit: Wikipedia

Global seafood demand is rising due to population growth and a shift toward healthier diets. Marine aquaculture, particularly fish farming, plays a crucial role in meeting this demand. From 1990 to 2020, global marine aquaculture production increased sixfold, reaching 29 million tonnes annually, and is projected to reach 74 million tonnes by 2050 [1].

Traditionally, fish farming has relied on open-net pens due to their cost-effectiveness [2]. Most of these open-net pens are located nearshore where they must compete with other users of the sea space. Moreover, elevated nearshore seawater temperatures resulting from global warming create hypoxic conditions that stress fish and can lead to increased mortality rates. Nutrient enrichment from open-net pen culturing and high stocking densities have led to frequent disease outbreaks and parasite infestations. These incidents have not only intensified public criticism of the fish farming industry but also resulted in significant economic losses, coastal environmental degradation, and biosecurity risks [3].

As fish farming continues to play a vital role in meeting the growing seafood demand and helping in the recovery of wild fish stocks, there is an urgent need to advance sustainable farming practices. This article reviews two promising solutions to replace conventional nearshore open-net fish farming: (i) floating closed containment systems, and (ii) offshore fish farming.

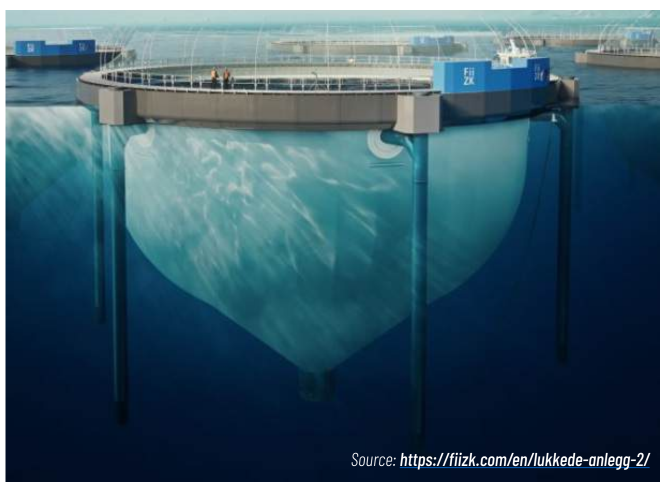
Floating Closed Containment Systems (FCCS)

Floating Closed Containment Systems have emerged as a promising solution, enabling fish farming operations to remain nearshore while effectively eliminating the problems associated with open-net fish farming. They provide a physical barrier between the cultured water and the surrounding marine environment, thereby significantly reducing the risk of disease transmission, preventing fish escapes, and minimising the environmental footprint of aquaculture operations [3]. By controlling water exchange, FCCS enable continuous disinfection to eliminate pathogens and maintain optimal oxygen levels for fish. External threats such as algal blooms, jellyfish swarms, and sea lice are effectively removed [4].

The physical barrier also prevents invasions from predators like seals and sharks. Organic wastes, including fish faeces, uneaten feed and dead fish, can be collected from the bottom of the containment systems and treated before discharge to the surrounding marine environment. Additionally, cooler water can be pumped from greater depths into the containment tank to prevent amoebic gill disease. Thus, FCCS can achieve higher production rates, with stock density reaching 30kg/m^3 compared to 10-15kg/m^3 in open-net pen systems [5], while also producing higher quality fish.

Types of FCCS based on tank rigidity

Containment tanks used in FCCS can be categorised into three types based on their rigidity: (i) flexible; (ii) semi-flexible; and (iii) rigid, each employing different construction materials. Figure 1 shows an example of a flexible containment tank, *Protectus*, developed by the Norwegian company FiiZK AS. The flexible containment system can retrofit existing open-net pens by replacing traditional nets with impermeable fabrics, such as Dyneema and polyester/PVC. Depending on the pen size, 4–6 independent water pumps are installed around the pen's circumference, drawing water from deeper layers. Each pump is equipped with oxygen injection, which is activated when dissolved oxygen levels are low. The system also includes a waste collection sump and outlet pipes, which pump and discharge solid wastes at a distance from the farming site.



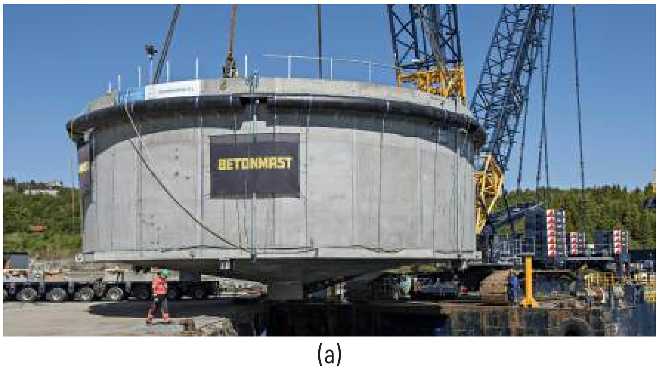
Source: https://fiizk.com/en/lukkede-anlegg-2/

Figure 1: Protectus flexible containment tank.

Figure 2 shows a semi-flexible containment tank, *Neptun 3*, developed by Aquafarm Equipment AS, Norway. It is constructed from lightweight Glass Reinforced Plastic (GRP) with localised reinforcement of high-tensile steel. The pump systems are mounted on linked floating stations. Water enters about 2m below the top of the tank, while outlets, controllable by flaps, are positioned around the perimeter about 1.5m above the base. The system was tested and found to have less than 0.5% mortality, zero escapees, no disease, and the ability to grow 118g smolts (young salmon) to 1.2kg in 6 months, while collecting up to 70% of organic waste.

Figure 2: Neptun 3 semi-flexible containment tank

A Norway-based marine technology company developed a rigid concrete containment tank, called *Salmon Home #1*. Figure 3a shows a trial tank which has a water volume of 1 000m^3, stocked with 60 000 smolts. The tank wall is 800mm thick, providing a solid walkway and space for pipes and pumps, while also ensuring sufficient buoyancy. The cylindrical tank is about 8m deep and 12m in diameter, allowing a stock density of 30kg/m^3. The intended full-scale unit has a 5 000m^3 capacity and can be arranged with multiple units on a concrete deck (see Fig. 3b).



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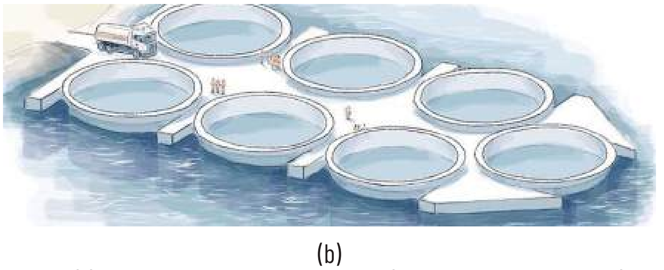


(b)

Figure 3: (a) Salmon Home #1 rigid containment tank (photo courtesy of Tor Ole Olsen) and (b) multiple units arranged on a concrete deck [6].

Types of FCCS based on water circulation methods

FCCS may also be categorised by water circulation methods: (i) Flow-Through Systems (FTS); and (ii) Recirculating Aquaculture Systems (RAS).

Most floating closed containment systems use FTS, which pump water from deeper sea layers to provide clean and cooler water enriched with oxygen. The water can be treated through various processes before entering the system to meet specific farming requirements. Similarly, the outflow can also be treated before discharge. A key advantage of FTS is that they maintain an internal water level close to the surrounding seawater level. They also benefit from natural cooling by drawing water from deeper layers, thereby reducing operational costs compared to systems pumping across different water levels or recirculating water.

In contrast, RAS continuously re-uses farming water and is commonly used for fish farming on land. They require minimal exchange with the external environment and thus have a higher control over farming water conditions and lower environmental impact than FTS. However, despite recycling water, water input is still required for operation, around 5% of the total volume per day [5]. In this context, FCCS for fish farming can offer easier and more sustainable access to water resources when compared to land-based closed containment systems with RAS.

Offshore fish farming

There is great interest in moving fish farms to offshore sites [7], which offer a more spacious and pristine water column, cooler water temperature, better water circulation, and waste dilution from ocean wave and current actions when compared to nearshore environments [8]. These offshore environmental conditions can reduce the risk of disease spread and parasite infestations that plaque open-net pen systems. However, offshore farming also presents new challenges, such as the need for the farming infrastructure and resilient fish to withstand strong surface waves. With these potential benefits and challenges, there has been a remarkable surge in research and development of offshore fish pens in recent years, driven by advancements in cutting-edge offshore technologies and strong national incentives from countries like Norway and China.

There are two main philosophies for offshore pen designs. One philosophy is to make the pens very large and robust to withstand the strong surface waves. The other philosophy is to make the pens flexible and submersible to avoid strong surface waves.

Large and robust pens

To withstand the high energetic offshore environments, fish pens can be designed to be large and robust. A notable example is Norway's *Ocean Farm 1* (see Fig. 4a), the world's first offshore fish farm with a fully automated system that combines semi-submersible offshore technology. This open-net pen fish farming facility is 69m tall, has a diameter of 110m, and can accommodate 1.2 million salmon. *Ocean Farm 1* is designed to withstand a maximum wave height of 8.4m. Another example is *HavFarm 1* (see Fig. 4b), the world's largest offshore fish farm, developed by a Norwegian salmon farming operator. It measures 380m in length and 59m in width, can house 2 million salmon, and is designed to withstand a maximum wave height of 10m.

China has actively promoted offshore fish farming by providing financial incentives, including covering 20% of capital expenditures and 70% of insurance costs. A notable example is *Gesheng 1* (see Fig. 4c), a semi-submersible fish farming platform measuring 86m in length, 32m in width, and 16.5m in height. It features an 800m^2 fishery operation platform, two fully rotating telescopic boom cranes, a sewage treatment system, a 140m^3 cold storage facility, a seawater desalination system with a daily output of 10 tonnes, and four berths for mooring service vessels.

(a)

(b)

(c)

Figure 4: (a) Ocean Farm1, (b) HavFarm1, (c) Gesheng 1.

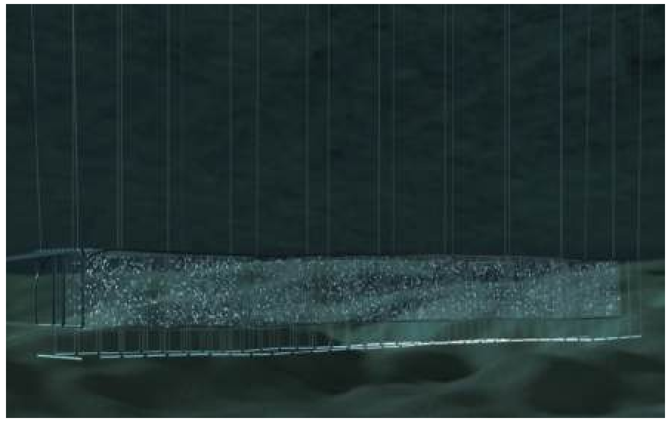
Sources:

(a) https://www.mn24.no/hitra-froya/i/x8kLgn/ocean-farm-1-transporteres-fra-froeya-til-verdal

(b) https://www.nordlaks.com/ocean-farm-jostein-albert/

(c) https://www.bairdmaritime.com/fishing/aquaculture/vessel-review-gesheng-no-1-intelligent-fish-harvesting-platform-to-be-deployed-off-chinas-zhuhai-province

Flexible and submersible pens



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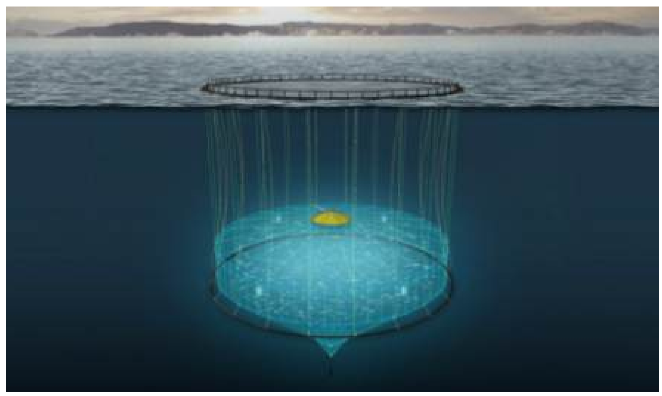

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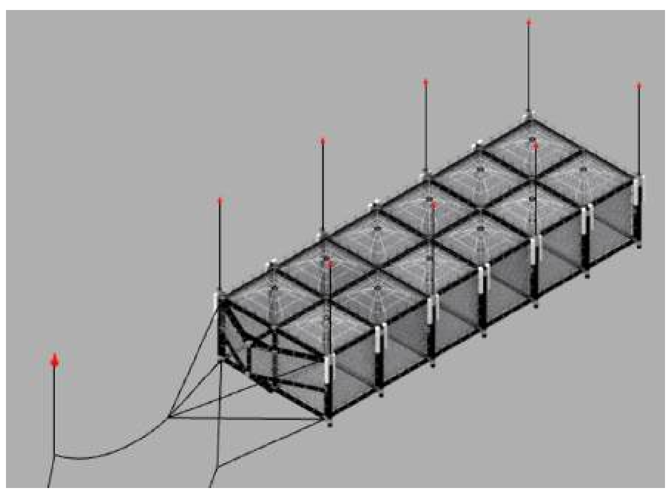

(c)

Figure 5: (a) SubFlex, (b) Nautilus, (c) SeaFisher [9].

Sources:

(a) https://www.youtube.com/watch?v=aC2IYMVuCF8

(b) https://www.akvagroup.com/nautilus/

By submerging flexible fish pens to optimal water depths, these systems can effectively mitigate the impact of strong surface waves during storm events. Notable submersible systems include Israel's *SubFlex* (Fig. 5a) and Norway's *Nautilus* (Fig. 5b). These innovative designs expand the possibility for fish farming in locations that are unsuitable for traditional open-net pens, particularly in areas exposed to intense surface waves or significant seasonal variations in marine conditions.

More recently, Australia's Blue Economy CRC team developed a novel offshore fish pen, *SeaFisher* [9] (Fig. 5c). The *SeaFisher* features a modular flexible High-Density Polyethylene (HDPE) frame secured by custom brackets and connector pods, offering durability, antifouling properties, and cost-effectiveness. It employs a single point mooring system, allowing it to function like a weathervane to reduce environmental loads and enhance waste dispersion. Its ballasting and diving support systems enable submersion up to 30m during storms, while a central buoy maintains power, air and feed supply.

Concluding remarks

Driven by public concerns about marine environmental impacts and increasing fish mortalities, the fish farming industry and government authorities are promoting sustainable marine fish farming using closed containment tank systems and moving fish farms offshore.

The use of FCCS is likely to attract more attention from the industry, as they can eliminate the risks associated with open-net pens while benefitting from staying in nearshore waters, thus reducing transport costs related to fish farming. However, FCCS require substantial power to circulate and re-treat water; this leads to 30% to 40% more production costs when compared to nearshore open-net farming [6]. Nevertheless, such additional costs could be judged in the context of the benefits of the use of FCCS. A report from the Scottish Aquaculture Research Forum [6] reported savings of 10 to 15% in production cost by reducing sea lice treatment. In addition, significant savings are expected from the prevention of fish losses and reduction of parasite infestation due to physical barriers. Furthermore, with advancements in artificial intelligence and automation systems, FCCS are expected to significantly reduce operational costs by optimising feeding processes and lowering mortality rates with better controllers.

Offshore open-net fish farming is emerging as an attractive solution to reduce environmental impacts while supporting the expansion of sustainable fish production. Offshore farming can lower production costs by leveraging economies of scale and adopting remote and autonomous technologies for monitoring, maintenance, and operations. Furthermore, co-location or integration with marine renewable energy facilities can further enhance economic viability through the sharing of infrastructure (such as mooring systems and service vessels), providing mutual benefits for both aquaculture and renewable energy sectors. This synergy can make offshore fish farming more economically competitive. However, public concerns remain regarding the risk of fish escapes inherent to open-net systems; also, the substantial capital investment required to reach an economically viable scale may pose challenges for fish farming operators.

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