which probably most commercially available pH meters are based is potentiometry. These devices have a glass membrane bulb at the tip of the sensor which is filled with a buffer solution and dipped into the relevant liquid for measurement. The hydrogen ions have a tendency to accumulate in a microscopically thin layer on the silicate groups of the glass surface. Since the H^+ ions are positively charged, depending on the difference in pH between the inner and the outer side of the bulb a galvanic voltage is generated which can be measured with two reference electrodes. One of the electrodes is located in the glass membrane bulb, the other is in a reference electrolyte.

The accuracy of a pH meter always depends on a number of factors, for example the ambient temperature during the measurements (the device should be equipped with a temperature sensor for temperature compensation), the charge state of the mobile energy source (exhausted batteries or too fast energy consumption can lead to incorrect results) or the exact calibration of the sensor and measuring instrument. In principle, pH measuring devices should be calibrated at least once per application. As a rule, two or three standard solutions with known pH values (usually an acidic pH 5 and a basic pH of 10) are used, to which the device is then calibrated.

It is particularly important that the pH sensor is correctly maintained and stored. It must never be allowed to dry out because the sensitive electrodes would otherwise be damaged and would not provide reliable values. If the electrode is not being used for measurements it should be rinsed clean and kept in pH-regulated water. Some manufacturers supply special storage solutions for the electrodes. When properly maintained, the electrodes of potentiometric pH meters can last for about 6 months. If, despite careful maintenance and calibration of the device, deviations in the measured values occur repeatedly the pH electrode must be replaced. Even in the case of expensive devices deviations up to ± 0.02 pH are often technically caused and tolerable; in the case of inexpensive handheld measuring devices the deviations can be larger. In principle, however, the following applies: the smaller the selected measuring range, the more accurate the pH measurement should be.

An alternative to potentiometric pH measurement with glass membrane electrodes are pH meters which function with ion-sensitive field effect transistors (ISFETs). This new and innovative technology allows very small sensors and has a short response time. ISFETs are semiconductor-based chemical sensors, the basic principle of which is approximately the same as that of the glass electrodes. Here, too, the hydrogen ions on the sensitive membrane of the transistor produce a voltage which changes the conductivity of the transistor which with the appropriate measurement technology can then be displayed as a pH value. *mk*

Offshore fish farming

Drawing on expertise from the oil and gas sector

Offshore fish farming has for some years now been considered a way to prevent some of the problems confronting coastal or inshore aquaculture. Offshore farming does have its own challenges, but these could perhaps be tackled using experience from the offshore oil and gas sector.

As world populations grow and agriculture struggles to keep pace, fish farming is becoming a vital source of future food production. According to US industry analysts Grandview Research, the global aquaculture market is estimated to generate revenues worth nearly US$203 billion (€190 billion) by 2020. In addition, the World Bank predicts that aquaculture will provide up to 62% of global food fish consumption by 2030[i]. And while China leads the way in aquaculture (supplying over half the world's farmed fish), the European aquaculture production market is also growing, accounting for 20% of global fish production and directly employing 85,000 people. The European Union remains the fourth largest global fish producer after China, Indonesia and India[ii]. Norway also remains Europe's leading provider of aquaculture products. In 2015, according to Statistics Norway, the country's official statistics body, the value of Norwegian fish farming was NOK46.7 billion (EUR5.2 billion) with a production quantity of 1.39 million tonnes - the vast majority being Atlantic salmon.

Inshore and coastal fish farming – the challenges of sea lice

Most aquaculture operations today are located inshore or in sheltered areas just offshore - the fjords in Norway, for example. The rise in consumer

[i] Fish to 2030, Prospects for Fisheries and Aquaculture, World Bank, 2013

[ii] The EU Fish Market 2015, European Commission

The expertise and technologies used in semi-submersible vessels in the offshore oil and gas sector can also be deployed in the development of fish farms.

demand for marine fish has spurred the growth of coastal farming operations, many of which are close to land with the benefits of being accessible and relatively inexpensive to run. There are number of challenges to 'close to the coast' fish farms, however, one key area being sea lice – small marine parasites that attach themselves to the fish and that are very difficult to get rid of. Such sea lice can damage the fish's skin, lead to secondary infections, reduce weight gain and – in the case of juveniles – prove fatal. The chemicals used to control sea lice or to treat infections can also lead to less healthy fish. It is against this backdrop that there has been a growing focus on taking fish farming offshore. What are the benefits of such farms and can they be made commercially viable through technology expertise?

The case for offshore fish farming

To date, only 2% of the global population's caloric intake comes from the world's oceans making the sea an obvious resource for further expanding aquaculture. It is also hoped that the deeper, free flowing waters miles offshore might limit exposure to lice infections and other contaminants. The more natural marine environment, predictable and steady water flows, and changing columns of water around the cages, the greater the potential for healthier, more profitable fish. But there are significant engineering and marine challenges to offshore fish farming today. Such challenges consist of the logistics of supporting such fish farms (maintenance, feeding, harvesting the fish etc.) through to the stability of the structures and whether they can be operational in harsh conditions.

Yet, while there may be a higher initial investment cost, once up and running operational costs can be significantly lower with greater potential profitability in the long-term. Most offshore fish farming processes are automated, for example, with just a handful of people required to operate a facility and most operations managed either on board or remotely, thereby minimising the use of service vessels and outside equipment. Over time, it is our belief that there will be a strong economic case for offshore fish farms due to increased demand for fish, technological developments, and - with the obvious available spaces - the potential economies of scale. This compares to the declining availability of inshore and sheltered coastal farming sites.

Learning from the offshore oil and gas sector

Another means of making offshore fish farming commercially viable is to borrow from already established expertise in the oil and gas sector. Although aquaculture is already borrowing from mono hulls and other ship designs, probably the closest comparison is in the design and deployment of semi-submersible vessels. These are anchored floating marine vessels that are secured to the seafloor and specialise in several offshore oil and gas activities, such as drilling, production, accommodating oil and gas personnel and acting as platforms for heavy lift cranes (among others). The expertise and technologies that enable such semi-submersible vessels to withstand challenging offshore environments can also be deployed in the development of fish farms. For example, these structures require the latest in structural engineering, including stability and structural strength analyses for transportation, lifting and installation; the measurement of fatigue life and in-place load regimes; risk-based structural assessments; mechanical analysis and design; and third-party verification. There is also a need for such semi-submersibles to have a small footprint to reduce exposure to waves.

Hydrodynamic analysis is also integral to the success of such projects, covering areas such as perform motion response analyses; the prediction of sea loads, including slamming and global load effects; and in the design and analysis of mooring systems. There are clearly strong areas of expertise in the offshore oil and gas sector that can be transferred into aquaculture but how does it work in practice?

The world's largest offshore fish farm

An example can be found in the world's largest fish farm - owned by Ocean Farming, a subsidiary of the SalMar Group, and that Global Maritime has played a key role in designing. Other partners in the project include the Norwegian Marine Technology Research Institute (MARINTEK), DNV GL who verified the design work, and Kongsberg Maritime who designed and delivered the power generation, automation controls and fish sensors. In addition to Global Maritime, both DNV GL and Kongsberg Maritime are key players in the oil and gas offshore sector. The facility, which will be located near the island of Frøya, Norway and will focus on salmon, is to be a permanently moored semi-submersible, anchor fixed structure with the capacity to raise 1.5 million fish annually and which is expected to enter operation in 2017. The experiences from this project will be crucial in the development of future fish farms worldwide.

Several key requirements for the new structure

Firstly, it would need to be highly stable with the minimum of movement during rough weather and yet provide the continued free flow of water; secondly, there should be no compromising of the space available for the fish; thirdly, there would need to be large volumes of water at significant depths to ensure fish welfare; and finally the facility would need to be developed as a commercially viable and cost-effective entity with limited maintenance requirements, durable structural components, and as much automation as possible. With these criteria in mind, Global Maritime designed a submerged, permanent, anchor-fixed structure, utilizing its offshore expertise and the same design principles as oil and gas semi-submersibles. The submerged part of the farm was fixed to the seabed by eight mooring lines and ballast tanks allow for inspection of the structure above water.

Layout and architectural expertise; structural engineering; hydrodynamics; stability and hydrostatics; weight estimation; and risk analysis were all skills and expertise used by Global Maritime in developing the farm. The result is an offshore fish farming facility operational in exposed locations and yet facing limited wave movements, due to a small water plane footprint (the facility has a diameter of just 100 meters). The life of the structure is estimated at 25 years and it is designed to survive ship collisions or a once-in-a-100 years wave. A vertical focus for the structure remained key with the semi-submersible operational in depths of between 100 and 300 meters and allowing for a water volume of 250,000 billion cubic meters (bcm). This provides the salmon with the opportunity to swim deep as well as providing the capacity for large numbers of fish, thereby increasing production and profitability. Sensor technology developed by Kongsberg Maritime will be able to able to accurately detect the fish's location in the vast water volume of the cage to ensure effective feeding. Stability was also vital with flotation tanks placed beneath the six vertical main columns as well as one moveable and two fixed bulkheads used to support the facility.

Automated operations and low maintenance

Streamlining operations to ensure profitability was also a key element of the fish farm design. For example, all farming operations are managed either on board or remotely, minimizing the costs arising from service vessel use. Regular cleaning of the nets is accomplished through automated spray nozzles with other features integrated into the design including a system for feeding and harvesting the fish and for removing dead fish. In all cases, heavier manual operations are avoided with a crew of three able to manage the whole facility.

Furthermore, by dividing the facility into three compartments, different fish operations can be performed, again increasing efficiencies and future profitability.

Writing new rules for the industry

Working with the Norwegian Directorate of Fisheries, Global Maritime has also helped develop and apply new rules and regulations to the project and the industry, based on existing marine and offshore shipping rules. This includes existing specifications surrounding marine systems and mooring analysis and collaboration with DNV GL, the international certification body. The resulting regulations were approved by the Norwegian Directorate of Fisheries and are likely to act as an industry standard for future offshore fish farms. Aquaculture and the move into offshore fish farming are integrating the best of technologies from both the fish farming and oil and gas industries. Working together, it's only a matter of time before offshore aquaculture becomes a key element of future food production.

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