The continued demand for crude oil supplies has driven oil companies to explore in increasingly remote regions, including under the seas and oceans around the globe.

Extracting oil from these offshore fields requires a means of getting the oil ashore. Traditionally, this has involved fixing a platform with production and separation facilities to the seabed over the well-head and then pumping the oil ashore through subsea pipelines.

As oil exploration has moved into deeper waters or where crude oil reserves are marginal, other, more cost-effective means of collecting and transporting the oil have evolved. For example, one way is to place a converted tanker—sometimes called a floating production storage offloading (FPSO) unit—over the well-head and then using shuttle tankers to take the oil ashore. Another option is to moor and connect floating platforms to the seabed and then transport the crude oil via shuttle tankers or pipelines.

All these methods have one thing in common. The structures or vessels must be protected from corrosion in a particularly aggressive environment. This applies especially to the fixed-leg platforms, which obviously cannot be brought ashore for maintenance when required.

The most corrosive environment for fixed platforms is the splash zone, the area above and below the tidal zone that is constantly subject to intermittent wetting and drying. These harsh environmental conditions coupled with the problems of access in order to repair damage that might occur after the platforms are installed mean that high-performance, long-lasting corrosion prevention systems must be used. This protection traditionall has been—and still is—provided primarily by the use of coatings.

This article reports on coatings used to protect splash zones of offshore platforms—primarily fixed-leg platforms—in the major offshore oil and gas-producing areas of the world. It was compiled from information provided by engineers and coating/corrosion experts who work for oil-producing companies or as consultants in the respective areas.

**Background**

Offshore oil and gas exploration has evolved from the drilling of wells in swamps and lakes in the USA and Canada starting in the 1920s. Now, this work has developed to the point that exploration and production can be carried out...
in ocean depths of greater than 1,000 m (3,300 ft).

Offshore platforms were first used in the Gulf of Mexico in the early 1930s south of Tampico, a city in Mexico, and then around New Orleans in the USA. Exploration for gas in the southern North Sea saw the first use of offshore platforms in Europe in the late 1950s. Exploration and production of oil and gas from the North Sea rapidly expanded northwards during the 1970s.

The other major production area to start using offshore platforms was the Middle East. Offshore production at Abu Dhabi started in 1958 and rapidly expanded throughout the region. Offshore production subsequently developed in many other areas, such as the waters around South America, West Africa, Indonesia, Australia, and in the Mediterranean Sea.

Many of the early platforms were located in shallow waters or were otherwise relatively easy to access for maintenance, two factors that influenced coating selection for the splash zone. For example, the early gas production platforms in the North Sea were located in about 30 m (100 ft) of water. The splash zones were generally protected with coal tar epoxies. These systems consisted of three coats with a dry film thickness (DFT) of 125–150 microns (5–6 mils) each applied to a surface that had been blast cleaned to Sa 2½ (the equivalent of SSPC-SP 10, Near-White Blast Cleaning).

The same coating system was used when larger, stronger platforms started to be built for use off the coast of Aberdeen, Scotland, where the water depth is about 130 m (430 ft). Similarly, the early Middle East platforms also used coal tar epoxy coatings. Platforms are now located in much deeper waters and they are more difficult to access. Therefore, the splash zone protection system must last longer before maintenance. At the same time, coating manufacturers have developed new products that are better able to withstand the aggressive splash zone environment. Thus, the coating systems used to protect splash zones have changed considerably over the years. The following sections highlight the types of coatings currently used for this purpose in various parts of the world.

Gulf of Mexico

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The platforms discussed in this section are fixed-leg and tension-leg platforms made of carbon steel.

The Gulf waters range from 60–3,600 ft (18–1,100 m).
Fixed-leg platforms are placed in depths up to 1,500 ft (458 m). Tension-leg platforms are placed in depths of 2,800–3,600 ft (850–1,100 m). The Gulf waters can be very violent. In normal operating conditions, the water can have intermittent waves of 6–12 ft (2–4 m), and, in hurricane season, waves can be 70–80 ft (21–24 m).

The splash zone ranges from 10 ft (3 m) below the main water line to 45 ft (14 m) above it. Water temperatures can range from 40–90 °F (4–32 °C), and the water and the air are, of course, salty.

It is impossible to completely remove salt contamination after blasting the surface during maintenance. Therefore, coatings selected must have some tolerance for salts. They must also be highly chemical resistant. When a rig moves onto location, chemicals such as caustic, calcium bromide, sodium carbonates, and hydraulic fluids are constantly present and can come into contact with the splash zone area.

For new construction, splash zone areas on carbon steel platforms are blast cleaned to SSPC-SP 5, White Metal (equivalent to Sa 3) with an anchor profile of 2–3 mils (50–75 microns). A two-coat system is used to protect the splash zone: an epoxy polyamide primer applied at 5–7 mils (125–175 microns) and a glass flake epoxy topcoat applied at 16–20 mils (400–500 microns).

The same two-coat system at the same DFT is specified for maintenance of the splash zones on both types of platforms, but the degree of cleaning specified is SSPC-SP 10 (equivalent to Sa 2½).

Other oil companies may use other coating systems.

**Historically, platforms in both the northern and southern North Sea have been fixed-steel structures that were fabri-**

### Splash Zone Protection of Risers, Conductors, and Other Elements

Under offshore conditions, increased temperature at the external surfaces of risers due to reservoir conditions can accelerate corrosion rates. It is not uncommon to see product temperatures in excess of 100 °C (212 °F). The temperature increase over ambient affects corrosion rates and presents arduous conditions for the coating system. Many systems that perform well at ambient do not perform well at these higher temperatures. Failures have also occurred. Any system proposed for application in wetted or intermittently wetted sections of risers and other appurtenances offshore must have appropriate heat resistance and be suitable for the intended service.

Under normal weather conditions, wave height is predictable and may not vary beyond 2–4 m (7–13 ft). However, under storm conditions, the variation will increase significantly. Structural components and appurtenances exposed to this harsh environment will need to be treated accordingly. In these areas, more robust coatings are required. Selection of such coatings should be closely considered at the design stage to avoid failures and maintenance problems.

In the case of protecting risers, selecting coatings for the splash zone is most critical. However, it is unnecessary and prohibitively expensive to treat corrosion protection of all sections of the structure with the same importance as protection of the splash zone. In the North Sea, ethylene-propylene-diene monomer (EPDM) rubber coatings are typically used for risers. These coatings require attention to detail in surface preparation and application, especially on the field joints.

Alternatively, risers have been protected in the splash zones with metal sheathing, typically Monel. Like risers, conductors are affected by temperature and, therefore, will require a more temperature-resistant coating system throughout the submerged and splash zones.

Although caissons, J tubes, and structural members require protection, they do not have the same need for corrosion protection as high-pressure hot risers, conductors, or gas and water injection and lift systems. Where temperatures are reasonably low or close to ambient, the materials specified for the splash zone of the legs may be employed. However, it has been normal practice to use a more robust material such as polychloroprene at 12 mm (480 mils) in thickness to protect against corrosion, scouring, and impact.

In the Bass Strait, the following practices also have been reported. Since 1980, all new risers for one company have been clad with Monel sheeting at a thickness of 5 mm (200 mils). Conductors are protected with 2–3 mm (80–120 mils) of a high-build epoxy. For coating old pipeline risers in situ, the following system is now standard for the same company. After surface preparation, the surface is primed with an ultrahigh-build epoxy at a dry film thickness (DFT) of 1 mm (40 mils). A petrolatum tape (1.5 mm [60 mils] thick) is then wound spirally onto the riser with a 55% overlap. Next, a high-density polyethylene (HDPE) jacket with a minimum thickness of 2 mm (80 mils) is strapped over the HDPE with plastic strapping material. An expanded polyethylene mesh is also secured with plastic strapping.

**North Sea: UK Waters**

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cated onshore and transported by barge or crane to the production or process site and piled into the seabed. Alternatively, steel-reinforced concrete structures have been used in both British sectors of the North Sea, but they have found more favour in the deeper waters of the Norwegian sector. These structures rely on gravity to hold them in place, which can be an advantage in deep waters because of the difficulty of piling into the seabed. In addition, they are quick to build, and they offer extensive subsea storage capacity in hollow areas of concrete. The subsea, splash, and atmospheric zones of most concrete structures are uncoated. Instead, they rely on high concrete density and thickness to prevent corrosion of the reinforcing steel.

A third option is floating structures moored and connected to well-heads on the seabed. These can be multi-hull structures built specifically for this purpose or converted tankers. They have become popular because they are less expensive than building fixed-steel or concrete platforms and more economical to operate in fields with marginal production. These units can be moved to another location when production in one area is finished. However, the focus here is on the splash zone protection of the first category of platforms—fixed-steel structures piled into the seabed.

Environmental Conditions
Water depths in the northern sector of the North Sea range from 120–180 m (400–600 ft) or more, which is considerably greater than in the southern sector where the depth is about 30 m (100 ft). Thus, the fixed structures tend to be correspondingly larger overall in the northern North Sea than in the southern areas. In both sectors, however, the upper water layer tends to be fast moving and highly oxygenated, which greatly enhances the corrosive conditions of this environment.

Corrosion control of the subsea zone of the platforms is achieved by means of cathodic protection or a combination of cathodic protection and coatings. The atmospheric zone, which is above the water level, is protected with a suitable coating system. The transition area between these two zones is the splash or tidal zone, which extends from just below the level of the lowest astronomical tide (LAT) up to a height in the atmospheric zone that is considered sufficient to protect against the effects of the elements.

The splash zone is typically 10 m (33 ft) in length, and it is difficult to protect because the applied coatings are subjected to aggressive conditions from waves, salt spray, wetting and drying, and scouring by floating objects. Thus, splash zone corrosion conditions can be classified as severe, with rates as high as 1 mm (40 mils) per year.

Newbuilding Coating Protection
As noted, the splash zones on the legs of fixed platforms originally were coated at newbuilding with coal tar epoxy. In the southern area of the North Sea, three coats of 125–150 microns (5–6 mils) DFT each typically were applied. For the larger platforms in the northern sector, three coats of 200 microns (8 mils) DFT each were used. In both cases, the steel was blast cleaned to Sa 21⁄2 (SSPC-SP 10) before coating. Coal tar epoxy also was used for maintenance coating work, but as a result of overcoating problems (coal tar epoxy became brittle and lost adhesion on ageing) and developments by paint manufacturers of more resistant products, glass flake epoxy coatings began to be used.

Therefore, from the mid-1980s to the mid-1990s, the conventional splash zone coating was glass flake epoxy or glass flake polyester applied at a thickness of 750–1,500 microns (30–60 mils) to steel blast cleaned to Sa 21⁄2 (SSPC-SP 10). In most cases, these coatings have provided good corrosion protection to the splash zone.

However, with the advent of CRINE and NORSOK, the economics and technical suitability of all coating systems were questioned. CRINE is the acronym for Cost Reduction in the New Era, an initiative by UK oil companies to standardise the design of equipment and specifications in order to reduce costs. Likewise, NORSOK, which stands for Norsk Sokkels Konkuranseposisjon (The Competitive Standing of the Norwegian Offshore Sector) is an initiative by the Norwegian Ministry of Industry and Energy to reduce design, construction, operation, and maintenance costs in the offshore industry. Part of this effort was to develop a coating standard for offshore installations. Today, many coatings are prequalified to this standard, NORSOK M-501, Surface Preparation and Protective Coating (System 7–splash zone). Most of these systems are surface-tolerant modified epoxies that are much thinner than the systems used before.

Surface-tolerant coatings offer a significant advantage over glass flake epoxy or glass flake polyester, since they are easy to apply and maintain. Also, a trend is developing to use the same coating system in the splash zone as in the submerged zone (but thicker in the splash zone). Fabricators favour this approach because it standardises coating products and equipment and minimises interfaces between different types of coatings.

For long-life situations or where the operator requires that maintenance be kept to a minimum, sealed thermal spray aluminium (TSA) is used. The superior long-term performance of TSA is well documented. It is generally accepted as a zero-maintenance system. Also, it offers a reduced corrosion allowance on all splash zone members, typically 3 mm (120 mils) compared with the conventional 12 mm (480 mils) corrosion allowance. On the downside, the system is a relatively expensive and requires specialised application equipment and operators. The major savings of a TSA system are reduced operating expenses because no
maintenance of the system is needed while the structure is in service. Nevertheless, it is considered to be affordable only when lifetimes are expected to be 20 years or more.

In cases where the growth of barnacles and other marine organisms causes stress on the offshore structure, an antifouling coating could be applied to a defined zone extending about 2 m (6.5 ft) on either side of the LAT.

In the extreme North Sea and in the UK Atlantic approaches off the northwest coast of Scotland, where water depth is in excess of 500 m (1,650 ft), floating production platforms are the norm. Their splash zones typically are protected with glass flake epoxy or glass flake vinyl ester at 1,000 microns (40 mils) DFT.

Maintenance Coating Protection

Use of abrasive blasting to achieve a high standard of cleanliness during maintenance of offshore platforms is difficult. Therefore, surface-tolerant coatings such as modified epoxies (epoxy mastics) are commonly used.

Since maintenance coating repairs in a splash zone involve a relatively low level of surface preparation and only a short period to make the repairs, it is not surprising that coating quality is variable. When cracking, undercutting, and spalling of the coating occur, the maintenance work must be repeated to provide the necessary protection.

Even for high-performance coating systems such as glass flake epoxy or glass flake polyester, it is assumed that at least two maintenance operations will be required in the splash zone over a 20-year field life.

To avoid misunderstandings, it is important to define “splash zone,” since different agencies and oil companies sometimes have different definitions, depending on where a platform is placed. The definition used here is the area from 3 m (10 ft) below the level of the lowest astronomical tide (LAT) to 3 m (10 ft) above the LAT. In the Norwegian sector of the North Sea, surfaces lower than -3 m (-10 ft) LAT are always protected by cathodic protection, and surfaces above +3 m (+10 ft) LAT are normally accessible for maintenance.

Coatings Only?

In Norwegian waters, corrosion protection of the splash zone is not normally provided by coatings only. A combination of coatings and corrosion allowance (i.e., thicker steel than found in other areas of the structure) is used. This is governed by the standard NORSOK M-001, Materials Selection, which includes the following formula for calculating corrosion allowance: increase in steel thickness expressed in millimetres = (design lifetime in years – 5) x 0.4 (plus an additional 2 mm [80 mils] corrosion allowance for each 10-degree C [18-degree F] rise in operating temperature).

It should be noted that the corrosion allowance can be reduced depending on the type of coating used, especially when there is a very high level of confidence that the coating will not be damaged during installation and/or operations. Polychloroprene is an example of such a coating type.

Different Coatings in Different Situations

The choice of coating will be affected by the temperature of the surface to be protected. In the oil industry, this can range from ambient temperature on platform legs to 100 C (212 F) and higher on hot riser surfaces.

At ambient temperatures, as noted, the required corrosion allowance of steel will depend on the type of coating system used. Thin-film coatings, such as 300 microns (12 mils) of zinc silicate and epoxy, will require the maximum corrosion allowance. However, by using 8 mm (320 mils) of polychloroprene, for example, the corrosion allowance may be considerably reduced or even avoided. Other coatings, such as 1–1.5 mm (40–60 mils) of glass flake polyester or epoxy, may result in a 30–70% reduction in corrosion allowance requirements. All of these coatings and several others, including TSA, have been used successfully for splash zone protection of platform legs at ambient temperatures in Norwegian waters.

In high operation temperatures, most risers are protected in the splash zone by using a thick (normally 12 mm [480 mils] minimum) polychloroprene coating even up to temperatures of 120–130 C (248–266 F). TSA with an aluminium-silicone sealer has also been used on risers in the splash zone on at least one project in the Norwegian sector. However, it remains to be seen whether this coating will provide acceptable coating lifetimes on surfaces with higher than ambient operating temperatures.

In the aftermath of the 1988 explosion and fire that destroyed the Piper Alpha oil platform in the North Sea, claiming 167 lives, several operators decided to protect risers against fire all the way down from the underside of the platform into the splash zone. Thus, the coatings had to provide corrosion protection plus fire protection and be strong enough to protect against damage by stormy seas and floating debris. Several solutions to this problem were...
developed in the ensuing years, including coatings based on polychloroprene and polyester with DFTs up to 25 mm (1 in.).

**Surface Preparation**

Due to the extremely corrosive nature of the splash zone and the difficulties related to maintenance of these areas, requirements for surface preparation prior to coating application are extremely high. It is seldom that a lower blast-cleaning standard than Sa 3 (the equivalent of SSPC-SP 5) is specified. A specific roughness is normally also required to ensure that the applied coatings will fulfill stringent adhesion requirements. The same requirements are applicable for newbuilding and maintenance work.

**Do It Right the First Time**

Maintenance of steel surfaces and coatings in splash zones is extremely difficult and expensive. Therefore, design of the structure is very important. An excellent example of designing correctly is when risers are flanged rather than welded (such as on tension-leg platforms), and the riser strings are designed so that the higher and lower flanges are not within the splash zone area. The lower flanges thus are protected by cathodic protection, and the higher flanges are accessible for maintenance, should this be necessary. The important message concerning the corrosion protection of splash zones is, of course, do it right the first time.

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**Middle East**

Offshore platforms in the Middle East are found in the relatively shallow waters of the Gulf, which is generally about 10 m (33 ft) in depth but ranges up to 30 m (100 ft) in places. The environment is very hot and humid, but the waves are not nearly as aggressive as in the North Sea.

Fixed-leg steel platforms are the most common offshore structures here, and the use of coal tar epoxy on splash zones is gradually being phased out as environmental and health legislation increasingly dominates coatings specifications. However, its track record of tolerance to aggressive application conditions as well as its track record of performance are proving hard to beat by the increasingly used high-build epoxy mastics. These coatings have a varying track record of success. There are those who advocate their continued use and those who do not. Where performance is lacking, it may be the result of poor application in the field. This may explain why high-build epoxy mastics are being used more for new construction than for rehabilitation and maintenance. System thickness of these coatings is similar to that of coal tar epoxy—300–400 microns (12–16 mils)—applied in a minimum of two coats and sometimes three. Although many products can be applied in one or two coats, difficulties in achieving the specified minimum DFT consistently make application of fewer coats impractical.

The general trend tends to be use of epoxy-based compounds rather than glass flake polyester variants for splash zone protection. Schools of thought vary between the glass flake polyester providing a mechanical key to subsequent coats of paint and being a source of wicking (absorption) in the humid Gulf conditions. Besides, glass flake polyester and glass flake epoxy tend to be more expensive than epoxy mastics, precluding their use in what has always been a cost-conscious environment.

The tendency is to always apply a holding primer because the blasted surfaces tend to become contaminated and flash rust quickly under hot and humid conditions. It is doubtful, unless under strictly controlled shop conditions, that anticorrosive pigment primers applied directly to steel will ever truly catch on.

Sa 2½ (SSPC-SP 10) is the typical blast-cleaning standard for both newbuilding and maintenance work in this region—although, as in other regions, it can be difficult to achieve this level in offshore maintenance work. Garnet is quite commonly used as the blasting medium because of its cleaning speed.

Higher sea temperatures here than in other regions promote the growth of marine organisms, particularly barnacles. Therefore, an antifouling commonly is applied on top of the splash zone coating system.

In summary, as in other parts of the world, environmental and health legislation is moving splash zone coatings towards the more environmentally acceptable epoxy variants. However, coal tar epoxy is proving hard to beat. The conversion process is likely to continue to be slow.

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**Mediterranean Sea**

In this region, the sea depth ranges from 30 m (100 ft) in the high Adriatic Sea to 120 m (400 ft) in the low Adriatic Sea. In the central Adriatic, where the depth is 850 m...
(2,800 ft), an FPSO rather than a fixed-leg platform is used. In the Mediterranean Sea itself, the depth is 200–300 m (650–1,000 ft).

The environment is characterised by high salt concentrations and sea water spray. The typical offshore platform has eight steel fixed legs. The jacket is 134 m (440 ft) high, weighs 17,000 tonnes, and has 900-tonne anodes. The deck weighs 2,700 tonnes.

Platforms in the Mediterranean Sea are used for two different purposes: drilling and production in the ratio of 5:95%. Generally, they originally are used to provide accommodation for workers during the drilling phase, which can last 6–10 months. Then the drilling rig is moved away, and the production equipment is installed.

Most platforms that have been in production in the Mediterranean Sea for a long time have their splash zones protected by one coat of solvent-free high-build epoxy at 1,000 microns (40 mils) DFT.

Recent inspections of these structures have found different situations, depending on the age of the platform. Generally, the quality of the coating is good between 5 and 10 years in service. However, after 10–12 years, the condition has usually deteriorated, and the coating is in need of maintenance. The maintenance work normally involves the use of surface-tolerant coating systems that are compatible with the applied system and suggested by the manufacturer of the original system.

The splash zone is located between a line drawn 4 m (13 ft) above the average level of the highest tides and one drawn 3 m (10 ft) below the average level of the lowest tides.

Nowadays, the splash zone is protected by high-performance paint systems. The ENI paint specification offers a choice of four coatings for new platforms:
- glass flake-reinforced polyester (two coats of 750 microns [30 mils] DFT each);
- glass flake-reinforced epoxy (two coats of 500 microns [20 mils] DFT each);
- epoxy ceramic (three coats of 125 microns [5 mils] DFT each); and
- thermal spray metallic coatings.

The required surface preparation is Sa 3 (SSPC-SP 10) above the surface roughness of coarse, as defined by ISO 8503 (Preparation of Steel Substrates Before Application of Paints and Related Products—Surface Roughness Characteristics of Blast-Cleaned Steel Substrates).

Before use, every paint system must undergo a series of prequalification tests, including a cyclic test (in accordance with ISO 7253, ASTM G53); condensation chamber test (ISO 6272); cathodic disbonding test (ASTM G8); water absorption test (ISO 62, ASTM D570); and abrasion resistance test (ASTM D4060).

Four types of platforms are found in the Bass Strait off the southeastern corner of Australia: steel jackets, steel gravity-based monotorwers, concrete gravity-based platforms, and subsea completions. This discussion will focus on steelwork, primarily on steel jackets, in the splash zone.

The conditions in the Strait are aggressive. The water depth is 40–95 m (132–314 ft). The water temperature ranges from 13–17 C (55–63 F). Currents are strong. Swells range from 1–4 m (3–13 ft) with waves of 0.5–5 m (2–16 ft). The prevailing winds, mostly from the west-southwest, are strong. The ambient temperature range is 10–25 C (50–77 F), while the relative humidity ranges from 60–100%.

Splash zone surfaces are defined in this setting as those of -4 to +7 m (-13 to +23 ft) mean sea level (MSL). For new construction, these surfaces are blast cleaned to SSPC-SP 10 (equivalent to Sa 2½) and coated with an ultra-high-build epoxy at a DFT of 2,000–3,000 microns (80–120 mils). Relative to coatings on other surfaces on the platform, the DFT of coatings in the splash zone is high. For instance, on most production equipment and other structural steelwork not in the splash zone, one coat of a high-ratio water-borne inorganic zinc silicate (HRZ) is applied at a DFT ranging from 100–150 microns (4–6 mils).

For non-splash zone surfaces requiring colour or gloss finish for safety or cleanability, the HRZ is applied as a primer, again at a DFT ranging from 100–150 microns (4–6 mils). An epoxy tie coat is then applied at a DFT of 40–60 microns (1.5–2.5 mils) followed by a catalysed acrylic gloss at 50–75 microns (2–3 mils) DFT.

For maintenance of the platforms, including the splash zone area above +0.5 m (1.5 ft) MSL, surface preparation is the same as that specified for new steel, and recoating is carried out with the same type of system originally applied. However, in the splash zone below +0.5 m (1.5 ft) MSL, various systems have been tried with mixed success. For example, petrolatum tapes were tried without success. Fibreglass-reinforced epoxy has had good results only on risers.

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