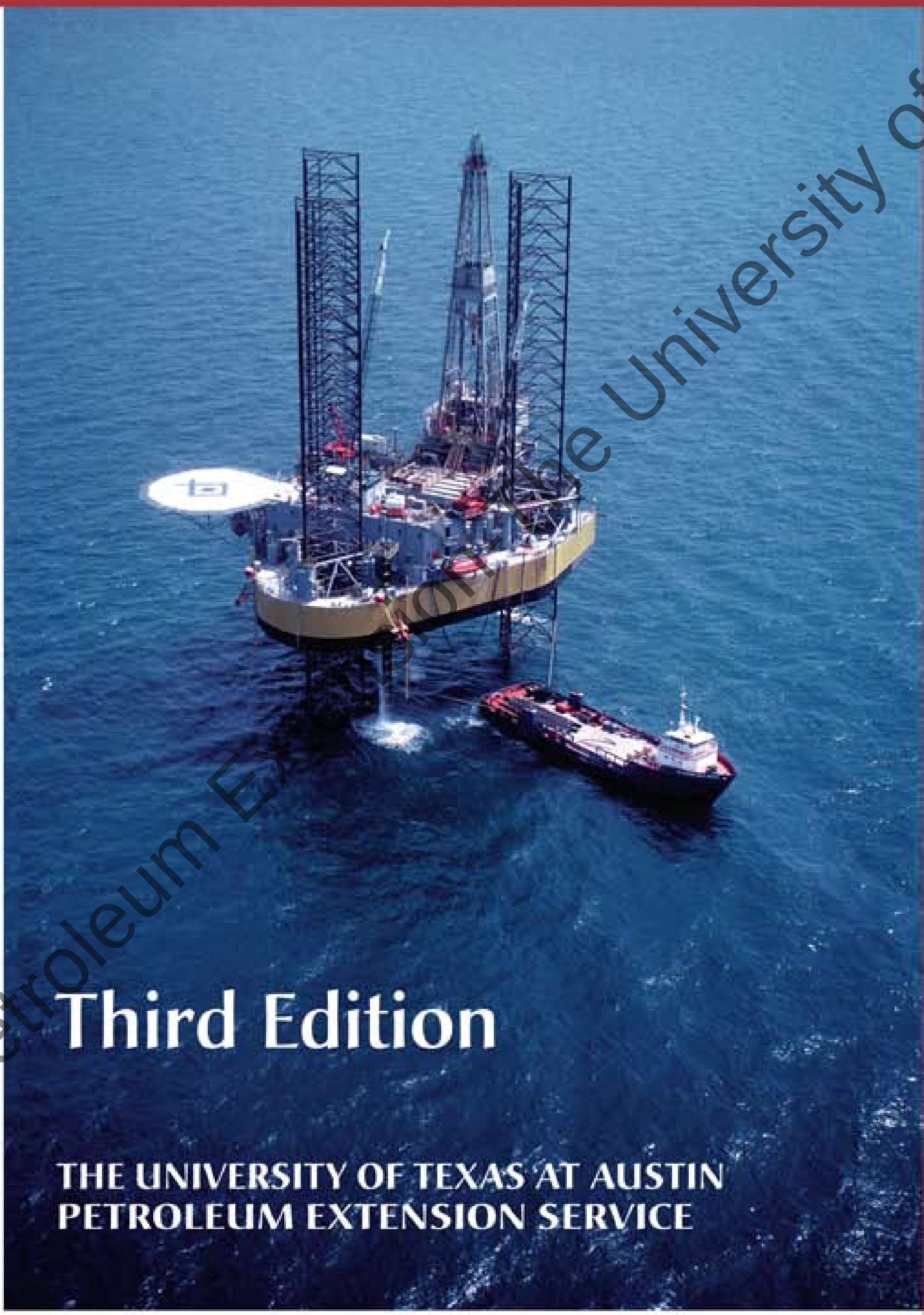
A PRIMER OF OFFSHORE OPERATIONS



Third Edition

THE UNIVERSITY OF TEXAS AT AUSTIN
PETROLEUM EXTENSION SERVICE

CONTENTS

INTRODUCTION

People use oil and gas more than any other source of energy. From oil, refineries make or extract gasoline, diesel fuel, and lubricants. Petrochemical plants make plastics and fertilizers. Natural gas heats our homes and fires steam generators to make electricity. Without oil and gas, everyone's life would be very different.

The petroleum industry produces oil and gas from special layers of rocks called reservoirs. Like a multilayered cake, additional beds of rock lie above and below these reservoirs. And, like the frosting on a cake, a relatively thin layer of ground sometimes covers the rock layers. On the other hand, the "frosting" may not be dry land; it may be water instead. Since oceans and seas cover about three-fourths of the earth, it is no surprise that water also covers rock layers.

Operating in oceans or seas—offshore—presents special problems to oil producers that they do not have to face on land sites. This book examines many of the special conditions the marine environment imposes on finding, producing, and transporting oil and gas.

First Offshore Operations in the U.S.

In the United States, offshore oil and gas operations began in the late 19th century. Edwin Drake drilled the first oilwell in the U.S. in 1859. He did it on a piece of land near Titusville, Pennsylvania. It was only thirty-eight years later, in 1897, that another enthusiast drilled the first offshore well in the U.S. He drilled it off the coast of Southern California, immediately south of Santa Barbara.

In the late 1800s, a group of people founded the town of Summerland, California. The founders picked the site because of its pleasant, sunny climate. Coincidentally, it also had numerous springs. These springs did not, however, produce water: crude oil and natural gas bubbled out of them.

Since Summerland could use gas to light its homes and businesses, and since oil could provide income, the city's residents took an interest in efficiently producing the springs. One citizen, H.L. Williams, was knowledgeable about extracting oil from the earth. So, just as Drake had done earlier in Pennsylvania, Williams drilled wells in the vicinity of the springs. The wells allowed him to extract more oil than if he had simply dammed up the springs. These early wells were successful and, as a result, he and others drilled many more in the area.

After drilling a large number of wells, these early oilmen noticed that those nearest the ocean were the best producers. Eventually, they drilled several wells on the beach itself. But, at this point, the Pacific Ocean stymied them. Experience convinced them, however, that more oil lay in the rock formations below the ocean. The question was how to drill for it.

Williams came up with the idea of building a wharf or a pier and erecting the drilling rig on it. The idea worked. His first offshore well, drilled from a wharf made of wooden pilings and timbers, extended about 300 feet (90 metres) into the ocean. On the end of the wharf, Williams erected a drilling rig and used it to drill the first offshore well in the United States. As expected, it was a good producer and before long the entrepreneurs built several more wharves (fig. 1). The longest stretched over 1,200 feet (nearly 400 metres) into the Pacific.

Figure 1. The first offshore wells in the United States

The Scope of Offshore Operations

Today, offshore activities take place in the waters of more than half the nations on earth. And no longer do primitive, shore-bound wooden wharves confine offshore operators. Instead, they drill wells from modern steel or concrete structures. These structures are, in many cases, movable. What is more, they can float while being moved, and often while drilling. Further, offshore rigs have drilled in waters over 7,500 feet (over 2,200 metres) deep and as far as 200 miles (over 300 kilometres) from shore. Offshore drilling and production have progressed far beyond those early efforts at Summerland.

Offshore work today involves a wide range of technologies. These technologies are similar in many cases to those used to find, produce, and transport oil and gas on land. Offshore activities include, however, additional technologies that relate to a marine environment. Unlike oil operations on land, offshore operations involve meteorology, naval architecture, mooring and anchoring techniques, and buoyancy, stability, and trim.

Drilling and producing oil and gas wells are important phases of offshore operations, but the scope goes further. Offshore operations also include exploring—looking for likely places where oil and gas may exist in the rock formations that lie beneath the surface of the oceans, seas, gulfs, and bays. In addition, offshore operations include transporting oil and gas—moving them from their points of production offshore to refineries and plants on land.

1
OIL AND GAS

Oil people often call crude oil petroleum. *Petroleum* comes from the Latin word for rock, *petra,* and the old Greek word for oil, *oleum;* petroleum literally means "rock oil." Petroleum is a good name for crude oil because it really does come from rock. The rocks in which oil companies find petroleum have special characteristics. Explorationists—those who look for oil and gas—sometimes have a hard time finding the special rocks. Usually, many other rock layers cover and bury them below the earth's surface. Like petroleum, natural gas also comes from special rocks buried far below the earth's surface. Frequently, gas occurs with oil.

Characteristics of Oil and Gas

Oil and gas are *hydrocarbons.* That is, oil and gas contain only two elements: hydrogen and carbon. (An element is a substance that consists of atoms of only one kind. At present, about 112 elements exist. Almost 100 of them occur naturally; nuclear scientists make the rest in laboratories.) Other substances, such as sulfur, carbon dioxide, nitrogen, and salt, may also exist with gas and oil, but the gas and oil are hydrocarbons.

CHEMICAL MAKEUP

Even though only hydrogen and carbon make up hydrocarbons, a hydrocarbon's chemical structure is not necessarily simple. Hydrogen and carbon have a great attraction for each other and can arrange themselves in simple or very complex ways.

Natural gas tends to be less complex than crude oil. As it comes out of a well, it is mainly methane (CH_4), which is the simplest hydrocarbon. Natural gas frequently contains heavier hydrocarbons such as ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}). In addition to hydrocarbon compounds, natural gas may contain other gases, such as nitrogen, carbon dioxide, helium, hydrogen sulfide, and water vapor.

Crude oils can be complex. They often contain not only simple hydrocarbons, such as methane, but also complicated liquid and sometimes solid hydrocarbons. The complex structure of oil can keep even advanced chemists occupied with studying it.

PROPERTIES

Methane (natural gas) is odorless, colorless, less dense than air, and flammable. Because natural gas is naturally odorless and so flammable, gas companies add a chemical to make it smell bad before selling it. This odorant allows you to smell leaking gas and thus avoid accidents.

Crude oil varies widely in appearance. Its color can range from pitch black to pale straw. In weight, or density, it ranges from very dense—denser than water—to very light, perhaps only three-fourths as dense as water. Its viscosity, or resistance to flow, ranges from solid, which does not flow at all, to very thin liquid—almost like water. Crude oil's odor can range from very pungent to almost odorless. And, of course, it is flammable, which is partly why it is so valuable.

2
EXPLORATION

In the early days of the industry, oil explorationists usually looked for oil springs and drilled their wells nearby. They soon learned to look for other surface features that might show the presence of a subsurface reservoir. For instance, they found that salt domes often created traps for oil and gas. So they looked for upward bulges in the surface that might indicate an underlying dome and drilled wells around it.

Today, however, the search is more difficult. The early oil operators quickly drilled all the relatively shallow traps that showed their presence on the surface. Deep reservoirs usually do not give any indication on the surface. Explorationists cannot therefore find them by direct observation. And offshore, where seas and oceans cover the seafloor, oil finders must depend entirely on indirect scientific methods—at least in the first stages of exploration.

Indirect methods of hunting for oil and gas depend on the fact that rocks have variable properties. For instance, different rocks have different magnetic properties, and some rocks are denser than others. Sensitive instruments can measure and record these properties and often locate subsurface formations that *may* contain hydrocarbons.

Emphasize the word "may," for even if an oil hunter finds a subsurface formation with the right shape or configuration, the formation may not have any hydrocarbons. The only way to find out for sure is to drill a well into it. In other words, indirect methods reveal only the possibility of a petroleum trap. To confirm that the trap holds hydrocarbons, oil companies use a direct method: they drill a well.

Before a company can begin drilling, however, the company's decisionmakers must determine where. They cannot afford to put a rig in an arbitrary spot; they have to have some indication that the spot holds promise. In the search for that spot, four steps may take place. First, the company may run a magnetic survey. Second, they may make a gravity survey. Third, they may carry out seismic surveys. Finally, if the survey results look promising, they may drill an exploratory well.

All four of these steps may occur in sequence, especially in prospecting for oil and gas on land. Offshore, however—where companies carry out most exploratory work from a boat carrying a large amount of equipment—they may run magnetic, gravity, and seismic surveys simultaneously.

Magnetic Surveys

To run a *magnetic survey,* the boat tows a magne- tometer in the water over the area of investigation. The *magnetometer* is a very sensitive instrument. It measures and records the magnetic forces of the rocks in the earth's crust. If the rocks are homogeneous—all pretty much the same kind of rock—the magnetometer record shows a fairly uniform magnetic field. But the magnetometer may record a distortion in the magnetic field. This distortion, an *anomaly,* tells surveyors that they have found rocks containing minerals that attract a magnet. Finding such rocks may indicate an area of promise.

Basement rock, an igneous rock that in many places lies under sedimentary layers, often contains minerals that are magnetic. Basement rock seldom contains hydrocarbons. Sometimes, however, it pushes its way upward, or intrudes, into overlying sedimentary rock. An intrusion of basement rock may create arches and folds, or anticlines, which geologists also call *highs*, in the sedimentary rock. These highs may serve as hydrocarbon traps.

Magnetic surveying is not foolproof. Sometimes it cannot detect known traps. For example, in the Gulf of Mexico, salt domes intruded into

3

DRILLING RIGS

Once a company has obtained the right to drill a *wildcat*, or *exploratory*, *well* to see if hydrocarbons exist, they must then select some type of drilling *rig*. More often than not, they will use a *mobile offshore drilling unit* (*MODU*; pronounced "moe-doo") (fig. 14).

Rig owners can move mobile offshore drilling units from one drill site on the water to another. A rig has to be mobile because, after it finishes drilling one exploratory well, a crew has to move it to another site—perhaps nearby, perhaps far away—to drill another.

Oil operators use two basic types of MODUs to drill most offshore wildcat wells: bottom-supported units and floating units. Bottom-supported units include submersibles and jackups. Floating units include drill ships and semisubmersibles (fig. 15). Of the many types of MODUs, operators and contractors use jackups, semisubmersibles, and drill ships the most. Jackups are the most common.

Figure 14. A mobile offshore drilling unit (MODU) *(Courtesy Sedco Forex Schlumberger)*

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DRILLING A WELL

A writer once described a drilling rig as a portable hole factory. He pointed out that the sole purpose of a rig was to make holes in the ground and, since drilling contractors had to drill holes at different locations, the rig had to be movable. He wasn't too far off the mark. A rig, be it large or small, on land or offshore, has one main job: drilling wells.

Bits and Drilling Fluid

The job of a rig and the people who work on it is to put a drill bit in the earth and turn it. A *bit* is a hole-boring device (fig. 37). Pressed very hard against the ground and turned, or rotated, it makes a hole. The teeth on the bit grind and gouge the rock into small pieces. These pieces of rock, or cuttings, must be moved out of the way so the bit teeth can be constantly exposed to uncut rock.

As long as the cuttings are moved out of the way, the bit can drill ahead. To move cuttings away from the bit, the rig pumps a special liquid called *drilling fluid*, or *mud* (fig. 38). Most often,

Figure 37. A drill bit has teeth to penetrate a formation to make hole.

Figure 38. Drilling mud is a special liquid essential to the drilling process.

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EXPLORATION DRILLING

Once the operator has acquired the rights to drill and has determined precisely where to locate the rig on the drill site, the exploration drilling phase of offshore operations begins. The operator first selects a rig. With the rig selected, the next step is to move it onto the site and actually drill the well.

Whether the operator hires a bottom-supported unit or a floater, the primary idea is to get the bit turning on bottom with weight on it while circulating drilling mud. Enough differences exist between the two types of rigs, however, that we will discuss them separately.

Throughout this discussion on drilling from bottom-supported units and floaters, you will read about typical operations. Keep in mind that specific drilling techniques vary from area to area; what works in one part of the world may not be suitable elsewhere. Basic techniques are similar the world over, however, and they are emphasized.

Selecting a Rig

Generally, companies can drill an offshore exploratory well from one of two types of rig. One is a bottom-supported unit, such as a jackup or a submersible. The other is a floating unit, such as a drill ship or a semisubmersible. The operator's choice depends on many factors, including water depth, load capacities, the weather and other environmental conditions, and rig availability.

WATER DEPTH

Water depth plays an important role in rig selection. For example, in deep water, over 350 feet (100 metres) or so, the operator usually selects a floating unit. The water is too deep for most bottom-supported units.

LOAD CAPACITIES

A drill ship can carry much greater deck weight than a semi. A semi's vertical columns do not displace much added volume of water as the rig is loaded. So, when crew members add more weight, the semi submerges more deeply into the water. A great deal of weight on the drilling deck of a semi affects its ability to remain upright, even in calm seas.

A drill ship, on the other hand, displaces a lot of water, with only a small additional push down into the water when loaded. Thus, it is not as likely to capsize when subjected to heavy loads. It can carry most of the equipment needed to drill a well and does not need to be resupplied as often as a semi does. Since it is less dependent on supply boats, it can operate in remote waters for long periods.

WEATHER AND OTHER ENVIRONMENTAL CONDITIONS

Weather conditions also play a large role in rig selection. For example, in relatively shallow water where a jackup or submersible would be suitable under calm conditions, a semisubmersible might be a better choice if the weather is adverse.

Most rigs working in the North Sea are semis because of the rough seas that prevail in that part of the world. Even though water depths often do not exceed a jackup's capabilities, rough seas make it difficult to get a jackup on location. Also, at times the sea runs so high that jackups cannot withstand the tremendous forces generated by the waves.

Because a drill ship floats on the surface, wave motion affects it more than a semi. Thus, for drilling in calm, remote waters, the operator would more likely select a drill ship instead of a semi.

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DEVELOPMENT DRILLING AND COMPLETION

If tests on an exploratory well prove favorable, the operator usually drills and evaluates several additional wells in or near the reservoir. These additional wells are *appraisal wells*. The operator drills appraisal wells to confirm further that the reservoir contains enough hydrocarbons to justify the enormous expense of developing it. If the appraisal wells reveal that the reservoir does indeed contain enough hydrocarbons, then development drilling may occur. *Development drilling* is the drilling of several wells into a reservoir to extract hydrocarbons discovered by exploratory wells and confirmed by appraisal wells.

Operators use many kinds of rigs to drill *development wells*. A common type in U.S. waters is the platform rig, which may be rigid or compliant. A *rigid platform* does not move with the motion of the wind and sea; a *compliant platform* does move. Operators also use mobile offshore drilling units to drill development wells, the same rigs they often employ to drill exploratory and appraisal wells.

Drilling Platforms

In 1947, off the Gulf Coast of Louisiana, an operator drilled the first offshore well out of sight of land. It was an exploratory well, but the rig that drilled it was not, strictly speaking, mobile. Borrowing ideas and technology from experiences in Lake Maracaibo, engineers hit upon a sort of hybrid design for an offshore rig. It was a combination of a ship-shaped barge and a fixed platform. A *ship-shaped barge* is like a drill ship, except that it is not self-propelled. The operator has to tow it to the site. A *fixed platform* is a structure made of steel or concrete, although manufacturers originally made some out of wood. The operator firmly fixes it to the bottom of the body of water in which it rests.

The platform that drilled the well in 1947 was relatively small—only large enough to support the derrick, rotary table, and drawworks. The rig builders drove several steel piles and creosote-soaked timber piles into the seafloor. They then built a platform across the piles to provide a deck for equipment.

The barge was a U.S. Navy surplus landing craft converted to contain the rig's engines, mud pumps, mud pits, crew quarters, pipe racks, and so on. A narrow walkway, a *widow-maker*, placed between the barge and the platform allowed the crew to move back and forth between the two. Operators soon began calling the barge a *drilling tender.*

The idea behind this combination barge-and-platform design was simple. After operators drilled the well from the platform, they could quickly tow the barge to a new location. Moreover, they could easily disassemble the small drilling platform and salvage most of it for use at the new site. Further, they could leave the basic platform standing and use it to house equipment needed to produce the well if they discovered significant quantities of oil and gas. The design proved to be a winner. Even today, you can still find drilling platform tenders (fig. 99).

As offshore drilling technology progressed, mobile offshore drilling units gradually replaced most platform tender rigs, especially for drilling wildcat (exploration) wells. Platform tenders established an important benchmark, however. They showed the feasibility of drilling development wells from a platform that an operator firmly attached to the seafloor.

7

PRODUCTION AND WORKOVER

Offshore production involves a wide range of techniques and equipment. The operator uses the techniques and equipment to get oil out of the reservoir and into a transportation system. As produced fluids flow up the well and to the surface, the operator has to separate oil, gas, and water, and must handle each according to its individual requirements. As a result, a typical production platform may have a large amount of equipment and several people to successfully extract, treat, and move oil and gas to shore for refining and processing.

Reservoir Drive Mechanisms

Natural pressure in the reservoir forces oil and gas to flow from a reservoir into a well and to the surface. The main sources of this pressure are gas, water, or both in combination. Four kinds of natural drive mechanisms occur with oil and gas: dissolved-gas drive, gas-cap drive, water drive, and combination drive.

Dissolved-gas drive is present when all or almost all of the hydrocarbons in the reservoir are liquid in its undrilled state. When the operator drills a well into such a reservoir, the well creates an area of reduced pressure. It is somewhat like jamming a straw into a bottle of liquid and sucking on the straw. Sucking on the straw reduces pressure and liquid flows up the straw. Similarly in a reservoir, reducing the well's pressure causes some of the lighter liquid hydrocarbons to become gaseous. The gas comes out of solution and, as it does, it drives oil into the well and to the surface (fig. 117).

Gas-cap drive results when a reservoir contains so much gas that all of it is not dissolved in the oil. Because gas is lighter than oil, it usually rises to the top of the reservoir and forms a cap over the oil. When the operator completes a well into such a reservoir, the gas cap expands. The expanding gas drives oil into the well and to the surface (fig. 118).

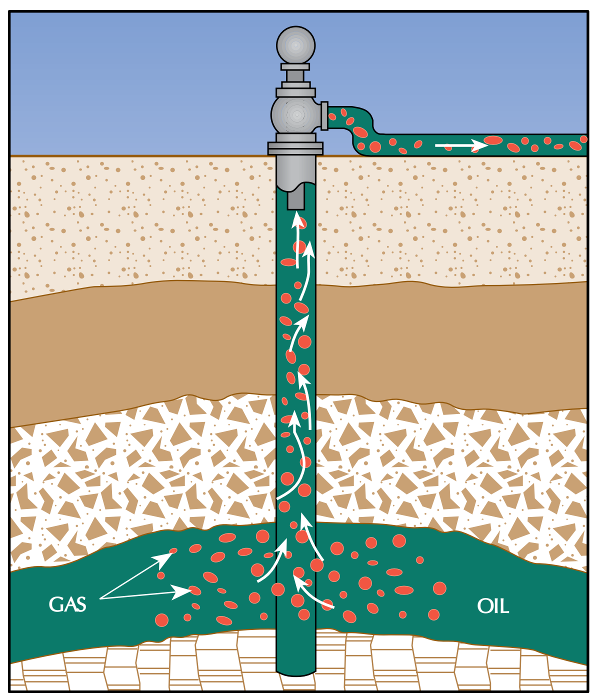

Figure 117. In a dissolved-gas drive reservoir, gas comes out of solution from the oil and drives oil to the surface.

8

OIL AND GAS TRANSPORTATION

After operators produce, separate, treat, and, in some cases, store oil and gas on an offshore production facility, they must ultimately send them to shore. Once on land, refineries and processing plants make products that practically everyone in the world uses. In general, companies transport oil and gas in two ways: in pipelines and in tanker ships.

Transportation by Pipeline

A *pipeline* is a series of connected pipes through which a company sends oil or gas. One end of the pipeline originates at a production facility and the other end terminates at a facility on shore. Pumps or compressors inject the oil or gas into the pipeline. Often, producers tie in several small-diameter pipelines from several platforms to a single large-diameter pipeline that runs to shore (fig. 135). The smaller lines are *tie-in pipelines*. The large pipeline is a *trunk line*.

Building an offshore pipeline is a complex operation. It often involves the laying of several miles (kilometres) of large-diameter pipe on the seafloor under adverse conditions. Further, a pipeline construction company may have to dig a trench to protect the pipe after they lay it.

A pipeline construction company lays these lines on the seafloor. Also, the company puts the lines into trenches if it is necessary to protect the pipe from damage by fishing activity or other marine work. Usually, the construction company coats all but the ends of the pipe with concrete. Concrete protects the pipe, helps prevent corrosion caused by seawater, and weights the pipe so that it will stay on bottom. The construction crew leaves the pipe ends free of concrete so they can weld the joints together. They then coat the welded joints to prevent them from corroding.

If the pipeline carries crude oil, the terminal on shore will probably consist in part of several large storage tanks. From these tanks, land pipelines send oil to refineries.

A gas pipeline generally terminates at a facility capable of processing the gas. Gas processing involves recovering the heavier hydrocarbon

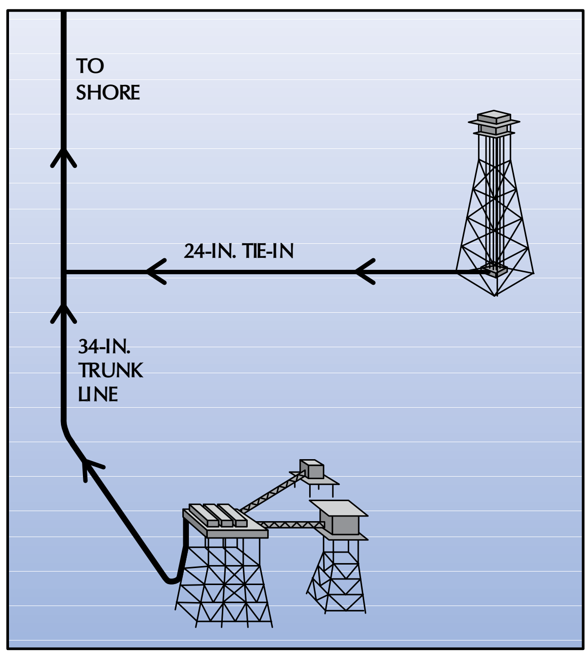

Figure 135. A tie-in pipeline joins a trunk line running to a shore facility.

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