GEOGRAPHIC FACTORS IN THE CONSTRUCTION AND OPERATION OF LIBYAN PETROLEUM PORTS

*by Robert W. Brown**

Since September 12, 1961 crude oil has been flowing out of Libya at an increasing pace which has made petroleum history. Libyans almost everywhere in the country have experienced the impact of the oil boom. The cities of Tripoli and Benghazi have come alive with new construction, and the vast reaches of the desert have become streaked with vehicle tracks and dotted with drilling rigs. Esso's Marsa el Brega, Oasis' Es Sider and Mobil-Gelsenberg Amoseas' Ras Lanuf are now the three leading ports of Libya by value and tonnage of exports; yet seven years ago not a sign of a ship or a ship facility marked their sites.

Libya's pipeline network has developed in a remarkable fashion. The wide dispersal of the Sirtica oil fields (Gialo is 330 kilometers east of Dahra) suggests that at least two gathering systems are needed for efficient distribution of the oil. The fact that there are three is due mainly to the provisions of the Libyan Petroleum Law. By fragmenting concessions among nineteen companies or groups of companies,[1] by encouraging active exploration through the territorial cession clause, and by levying a premium surface rent of £ 2500 per 100 square kilometers on concessions with established commercial fields, the law has spurred oil companies to construct pipelines and terminals to serve their own needs at the earliest possible date. Esso planned Libya's first pipeline in response to the discovery of the Zelten field, officially labeled as com-

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1. Fifteen new concessionaries were added in the grants of February, 1966.
2. The actual date of the discovery well was June, 1959; as in succeeding cases, the company started development plans before official commercial date.

mercial on September 1, 1959.[2] Oasis' first commercial field was Dahra, the official date being June 28, 1960, and the company started a second pipeline 180 kilometers to the west. Amoseas' Beda field and Mobil. Gelsenberg's Hofra were commercial finds as of April 1, 1963, long after the Esso and Oasis systems had commenced operations. Utilizing a clause in the petroleum law[3] that provides for one company's sharing another's pipeline and terminal if the capacity is available, Mobil. Gelsenberg and Amoseas quickly built spur lines to the nearby Oasis network and exported through Es Sider. But their discoveries merited the insurance of an individual system, which began to emerge in a form almost precisely like that of Oasis and at no point more than forty kilometers away from it. The Libyan pipeline pattern has become even more intriguing with the 423-kilometer sweep of Oasis lines into Concession 59 E, passing within thirty kilometers of Esso's line from the new Jebel field to Zelten. Mobil's second pipeline, running from Amal field to Ras Lanuf, actually crosses the Esso system. Meanwhile British Petroleum and Nelson Bunker Hunt elected to avoid the entire Sirtica complex and send their line over the Calanscio Sand Sea to Tobruk.

Thus have four independent pipeline systems developed, creating unusual patterns and making use of no common facilities. If the initial planning could have been based on today's knowledge of oil field locations, the pattern might look quite different.

The Gulf of Sirte Coastal Region

The three existing terminals are located on a coastal plain of steppe vegetation having few permanent settlements. Except for a small zone around the town of Sirte, rainfall averages less than 150 millimeters annually, and the ground water generally varies from brackish to salty.[4] The surface is marked by very little relief, and the sediments, strongly limey in character, have rarely hardened into a firm, usable rock. In the 700 kilometers between Taorga and Qemines there is not a single community that subsists on irrigated agriculture, and the only significant towns, Sirte and Agedabia, are more than 400 kilometers apart. This is

3. Article 12 of the Law of 21st May, 1955.
4. James R. Jones,

Bedouin grazing country—camels, sheep, goats and donkeys utilize ground water wells and cisterns scattered over the plain and convert the short grasses and shrubs into usable proteins for human consumption. Aside from this activity, a little fishing, and a very few small oases, the Gulf of Sirte coastal region provides no resources to support permanent human occupance.

A particular feature of the area is the pattern of winds. The spring ghiblis, well known to all residents of Libya, blow with particular intensity in the gulf coast, their force unbroken by protective vegetation to the south. Visibility is often impaired by the heavy loads of dust in the air. In the winter months the prevailing winds are from the northwest; Mediterranean storms increase in intesity as they advance to the southeast, carrying ever-larger wave swells with them. The very shape of the Sirte suggests the action of these winter storms. During the summer months the winds are milder, blowing predominantly from the northeast.

But in spite of unfavorable winds, scarcity of water, remoteness from population centers and other problems, the Gulf of Sirte coast has become the site of three major petroleum terminals. The oil companies had to decide on how to build harbors where there were none, on what services and equipment to provide, on the nature and number of housing units, on the methods of producing fresh water and electric power, and especially on the design of petroleum loading facilities. Where there was absolutely no economic infrastructure except the coast road, the companies had to supply all of their needs with the most efficient use of funds and time. How the companies dealt with the geographical conditions in the Gulf of Sirte in building and maintaining their terminals is the subject of this paper.

Selecting the Site

While the loading of crude petroleum is an automated procedure that requires far fewer facilities than handling bulk cargo, there are a number of site qualities which are important. Ideally, a sheltered, deep-water harbor is desired, but there is none to be found in the Gulf of Sirte. Rather than incur the tremendous expense of constructing such a harbor, all three petroleum companies elected to use open sea berths, and for these they sought deep water close to shore. In order to provide rapid loading by gravity they looked for high ground upon which to construct the oil storage tanks. They also need a small harbor for the line-handling launches which aid tankers in berthing; a site which permitted the construction of such a harbor at relatively low cost was also a requirement. Probably most important of all considerations was access of the terminal to the large producing oil fields. With pipeline costs inflated by the occasional need to blast rock for burying and by the need to truck pipe sections from Tripoli or Benghazi or unload them under difficult conditions at the terminal site itself, the companies wanted to keep the lines as short as possible. Furthermore, the shorter the pipeline, the sooner operations can begin, provided the terminal is also ready.

Esso had first choice in selecting a site. Drawing a straight line north from Zelten field to the coast leads one into the southeastern sector of the Gulf of Sirte, and here Esso found Marsa el Brega, an abandoned harbor village with a long history. In recent years it had witnessed unhappy times; in the 1930's it served as a concentration camp for Jebel Akhdar tribesmen,[5] and during World War II it had been the scene of heavy fighting, which had left some half million land mines as a legacy in the area.[6] While Marsa el Brega provided an elevated site for the tank farm and the foundation for a harbor large enough to receive cargo vessels, hydrographic surveys revealed an important shortcoming in the site. Marsa el Brega's location in the southeast of the Gulf of Sirte exposed it to the maximum development of the winter Mediterranean storms, whose winds and high wave swells could easily halt all petroleum loading activities in the open sea berths. While Esso considered other sites, none offered such good harbor potential, and the pipeline would have had to be notably extended in order to achieve any significant gain in weather protection for the sea berths. Hence Esso chose Marsa el Brega, leasing twenty-eight square kilometers from the

5. Esso Standard Libya, "Marsa el Brega - A Guide." 1964.
6. P.T. Modine, "Libya's First oil Pipeline," in **Oil and Gas International,**

Libyan government, enough to include an airport site and adequate room for industrial expansion, if the need should arise. As in the case of the other terminals, the Libyan government reimbursed local tribes for the use of the land.

Oasis' Dahra field is more conveniently located in Sirtica than is Zelten. Oasis' initial pipeline could be shorter than Esso's, and its terminal would be somewhat less exposed to the full fury of Mediterranean storms. But a reasonable radius from Dahra leads to no trace of a natural harbor; the company would have to depend on a small headland and reef for a harbor foundation. Considering three rather similar sites, Oasis settled on Ras es Sider, which offered a headland, deep water close to shore, an escarpment several kilometers inland upon which the storage tank farm could be built, and a convenient ridge near shore to hold housing and industrial areas. As in the case of Esso, an airport site was readily found on the leased land.

Mobil-Gelsenberg and Amoseas, with Mobil as operator, searched the same area of the Gulf of Sirte for a terminal site two years after Oasis had selected Es Sider. They chose the headland of Ras Lanuf, one of the sites previously considered by Oasis. Here the natural conditions are very similar to those at Es Sider, which is only twenty-five kilometers to the northwest. The tank farm site is higher at Ras Lanuf (see Table I), but it is also two kilometers farther from shore. Mobil's industrial and residential site is the same ridge formation as that of Oasis, but again it is on higher ground farther from the beach. Unlike Marsa el Brega, both Es Sider and Ras Lanuf appear to be pioneering settlements, there being no modern or archaeological evidence of previous human occupance.

Constructing the Harbor

Having found an oil field which quickly proved to be a major producer and having located a terminal site with good harbor potential, Esso planned Marsa el Brega as a multiple-function port from the beginning. Not only would it export oil, but it would import cargo for use on site and for distribution to oil camps inland. The company felt that an asphalt road accompanying its pipeline network would be a valuable long-run investment; hence Marsa el Brega would have a special offshore berth for unloading liquid bitumen by submarine pipeline to a storage tank on land. The power supply at Marsa el Brega would serve the Zelten camp as well; high voltage lines leading 174 kilometers inland. As plans progressed, including the development of the Raguba field in Concession 20, a small refinery was to be incorporated in the Brega complex to serve the entire Libyan market for the most-used petroleum products.

Constructing the harbor at Marsa el Brega was therefore an important undertaking. A 500-meter peninsula was extended and enlarged with local limestone, which was later buttressed with scrap metal on the seaward side to retard the effects of wave erosion. For the breakwater itself Esso Libya engineers designed one-piece 2200-ton cellular concrete caissons, each having dimensions of approximately 33 by 13 by 15 meters. Fourteen of them were prefabricated in Italy and towed to Brega by tugs, where they were sunk into place to form an L-shaped wharf.[7] 750,000 cubic meters of sand were dredged from the harbor to provide room for cargo ships with a twenty-four foot draft. In 1963 the shallow portion of the harbor was partially closed in with the addition of a second wharf extending 300 meters north from the shore. Constructed of twenty-two steel cells filled with sand, this jetty was designed to give greater protection for small boats and industrial facilities and to increase docking space for shallow-draft ships. It provided the added benefit of alleviating the accumulation of seaweed in the harbor, which previously had been periodically removed on barges and dumped at sea.

With a timetable less than one year behind Esso's, Oasis was constructing the Es Sider terminal when Esso shipped its first oil. Oasis planned its site for a single-function port only, the harbor to serve for sheltering mooring launches and other small boats. Oasis and their contractors elected to construct their causeway and breakwater from local

7. Esso in Libya, 1965.

materials rather than importing prefabricated units; and on June 12, 1961, the first load of limestone was dumped on the Es Sider headland to form a curved jetty. Unfortunately, it was found that the stone from the first quarry was too soft to withstand the action of the sea; a second quarry, eight kilometers from the port, proved to have more durable limestone. But even this rock was eroded on the seaward side, requiring a supplementary measure utilizing imported materials. Cement from Yugoslavia and Sicily was mixed with the local aggregate and salt water to make concrete, from which seventy-two tetrahedron molds were formed in the ground at the site of the original limestone quarry, only a few hundred meters from shore. Engineers then fabricated more than 2000 concrete tetrahedrons at a maximum rate of twenty-two per day, dropping them on the seaward side of the breakwater to absorb the brunt of wave action.

When Oasis planned to build its long pipeline to the rich new fields in Concession 59, the company decided to give Es Sider a second function. Early in 1964 a 200-meter limestone jetty was extended north from the shore in order to permit offloading of pipeline sections to be transported inland. The procedure was carried out under difficult conditions in this shallow-draft area, however.

Oasis has been faced with an unpleasant surprise in the maintenance of its harbour. Observation has shown that the longshore currents are westerly in the Gulf of Sirte, and the easterly-oriented Es Sider harbor, with its breakwater built up on a natural headland, is situated in such a way that it traps large quantities of sand and seaweed carried by the moving waters. The rapidity of accumulation has required daily dredging, performed by a contracting company using shovel and barge. In 1965 Oasis invested in an American suction dredge to perform the job more economically. Meanwhile marine consultants have made tank tests to seek a reasonable solution, but none has yet been found.

Mobil with its partners, though given third choice in site selection, had two important advantages in the development of its terminal: it was able to profit from the experience of its competitors, and it was able to export oil through the Oasis network during the construction of the Sirtica Pipeline and Terminal System, owned jointly with Gelsenberg and Amoseas. The time gained thereby was utilized in careful study of the problems to be faced. Like Oasis, Mobil planned a single-function terminal with a harbor for small boats only. Determined to avoid Es Sider's silting problems, Mobil commissioned a Dutch firm to design the harbor. After studying hydrographic conditions on the coast at Ras Lanuf, the company reconstructed the situation in miniature, building a total of nine different harbor models to test their performance in winds and currents. In conclusion the breakwater was designed to nestle in the lee of the headland rather than to rest on top of it, thus utilizing the headland to deflect currents from the mouth of the harbor.

Like Esso, Mobil chose to prefabricate the support units of the breakwater. Steel cells fifteen meters in diameter were preformed in the Netherlands, assembled on site, filled with local rocks, and capped with concrete. The outer edge was beveled to deflect the force of the waves. In the 300-meter causeway leading from shore local rocks formed the base, while about 300 concrete tetrahedrons, smaller than those at Es Sider but similarly formed, were used to strengthen the weakest area. During construction a thirty-meter addition was included in order to provide space for unloading pipeline to the new Amal field. Another modification was the use of backfill in the harbor in order to reduce swells in the dock in heavy weather. With a one in five gradient the backfill cut wave heights from fifty centimeters to ten inside harbor.

While Mobil's approch to harbor construction involved considerable sacrifice in time and expense, it has resulted in a very attractive installation which has so far remained remarkably silt free. Having opened in June of 1965, six months after the first shipment of oil from Ras Lanuf, the harbor has not yet stood the test of time. One wonders if the seaweed and sand now accumulating on the nearby shore will have any long-range effect on the performance of the harbor. Mobil wonders, too; the company has commissioned a study to try to determine the answer.

Petroleum Loading Facilities

The general procedure for receiving tankers and loading petroleum is similar in all three ports. Upon arrival in the berthing area the tanker receives one of the port's experienced mooring masters on board to guide the ship into position. When the tanker is secure— accomplished with the aid of launches and, in the case of Marsa el Brega, a tug—she must spend several hours pumping salt water ballast from her tanks. Extensive precautions are taken to insure that none of the ballast water pumped overboard contains petroleum, which contaminates the beaches; each port maintains its own system for inspecting incoming tankers. When the deballasting procedure is finished, the tanker can take on its load of petroleum. Maximum speed of loading varies with the size and facilities of the tankers; smaller ships many load at 10,000 barrels per hour, while the new supertankers can accept up to 50,000 barrels per hour. Oil flows from the tank farm to a meter battery, where precise measurement occurs. The oil lines then divide, one going to each sea berth, passing first over land and then underwater to a floating buoy, whose flexible lines are attached to the tanker's loading valves amid-ships. Before and during the loading, inspections for oil quality and quantity are performed by company personnel, Libyan customs officers and a representative of the Libyan Ministry of Petroleum Affairs. With her tanks filled with oil and the necessary papers signed, the tanker can leave port, usually eighteen to twenty hours after she comes in.

The three terminals were designed to permit this procedure to occur with maximum speed and efficiency at any hour of the day and under almost any condition of weather. While the sea berth itself is the ultimate key to successful operation in heavy weather, the port's other facilities are also important in the loading process. Tankers load petroleum intermittently while field production is nearly constant; hence there must be sufficient storage space in the tank farm to allow continuous production in the inactive periods, including those necessitated by storms. Speed of loading petroleum may be ultimately dependent upon the port's ability to provide adequate flow from the tank farm to the ships, especially if several ships are loading at once. The ports are therefore equipped with large diameter transfer pipes and, if gravity does not provide enough presure, pumps to increase the speed of flow.

While two companies have introduced technological variations in sea berths, all three of them have utilized three berths of the standard submarine type. Under this system five or seven buoys are distributed in a semicircle, each to receive a line from the ship's stern. To enter the berth the tanker approaches the open end, following a series of markers lined up on shore or in the open sea. As she pays out one anchor from the bow, she moves across the berth and pays out the other anchor, subsequently heaving in on the first while maneuvering into final position. The docked ship is oriented in one direction only, and if strong winds blow hard on the beam during the mooring process, it may be impossible to swing the ship into position. Heavy swells can also disrupt the procedure. Because of the fixed orientation and the need for a complex swinging maneuver in order to moor a ship, the submarine berth's capabilities in heavy weather are clearly limited. Its advantages lie in simplicity of construction and maintenance.

Marsa el Brega, pioneer port and the leader in total petroleum delivered, began operations in September of 1961 with four storage tanks and one sea berth. Additions in increments of four have given the port sixteen tanks of 268,000 barrels' capacity each, a total of 4.29 million barrels in storage, equivalent to about seven and a half days' production (see Table 1). The fire caused by sabotage in July of 1965 destroyed three tanks and Esso had to face the winter of 1965-66 with storage space for only six days' production. The tank farm is at an average altitude of forty-three meters. A forty-eight-inch pipeline runs five and a half kilometers to the meter battery, whence all four sea berths have separate lines, thirty-inch pipes going to berths one and two and forty-two inch pipes to berths three and four. Gravity flow permits maximum loading rates of 55,000 barrels per hour to all ships combined or 35,000 barrels per hour to one ship in berth three or four. A pumping station installed in the fall of 1965 increases these maxima to 100,000 and 60,000 barrels per hour, respectively.

Three of Brega's berths are of the standard submarine variety. Standing in about forty-four feet of water and 1500 meters from shore, berths one and two are capable of handling ships with a displacement up to 50,000 deadweight tons. Both are oriented 330⁰ True, pointing the ships toward a swept channel leading past the reef to the open sea. This heading is also a good compromise for meeting the heaviest winds and seas in the winter months, which are most frequently, but by no means universally, from the north and northwest. Berth four is also a submarine installation, situated to the west of the harbor at a distance of two kilometers from shore. In seventy-two feet of water, berth four can accommodate supertankers up to 300 meters in length. Originally oriented at 330⁰ when inaugurated in Novembers of 1963, berth four has been reorientend to 295⁰ in order to meet the gale-force winds that sometimes develop in this quadrant. The new orientation, as well as the less restricted approach, has enabled berth four to remain open in some storms when berths one and two were closed.

Recognizing from the beginning the limitations of the submarine berth and the exposed location of Marsa el Brega, Esso engineers immediately started work on a new design for a mooring berth, one in which the ship would tie up at the bow and swing freely into the wind, even while loading oil. Such a mooring would also be easier to approach, requiring only forward motion by the tanker and no anchoring. Installed at Marsa el Brega in June of 1961, Esso's bow mooring (berth three) consists of a fixed pylon surmounted by a revolving boom, from which is suspended a 170 meter submerged oil loading pipe arm. The pylon is surrounded by a fender ring, mounted on steel piles. The submerged loading arm is propeller driven to the ship's midsection, where hose connections are made.

After an initial development period of a year and half the bow mooring was officially inaugurated in February of 1963. It has been under constant study and evolution since, occasionally being closed for modification or repair. While Esso does not claim to have produced a flawless design, the new device has succeeded in reducing average mooring time from two hours to one. In the case of one small tanker a twelve-minute mooring time was achieved. Moreover, the bow mooring has often loaded tankers in heavy weather while the other berths were closed. The hours saved by the bow mooring have increased each year with its improvement. A problem with the design is the sensitivity of the oil-loading pipe arm to the action of ocean currents, which at Marsa el Brega are generally westerly, often conflicting with the winds. In order to avoid damage to the loading arm, the bow mooring has been closed under conditions where ocean currents tend to carry the boom into the path of an approaching tanker.

As the first design of its type in the world, Esso's bow mooring has attracted much publicity in petroleum publications. Bow loading tankers are now under development to take maximum advantage of this new principle in loading; they will eliminate the need for a submerged pipe arm, thus solving the major problem in Esso's installation. The bow-loading principle is eminently suited to be used with the monster super-tankers of 200,000-300,000 tons now on the way; as the technology changes, Esso's high development costs for the bow mooring — two or three million pounds — will certainly appear justified.

By the fall of 1965 Es Sider was exporting petroleum at a rate comparable to that of Marsa el Brega, and its loading facilities were quite similar. Fifteen storage tanks hold four and a half million barrels, equivalent to almost eight days' production at the end of 1965. The tank farm sits on a seventy-three meter escarpment at a distance of six kilometers from the meter battery, the oil traveling the distance in three forty-two-inch lines. The submarine lines to the four sea berths are all thirty-six inches in diameter. The hydraulic gradient from the tank farm to the shore is about 1 to 100, similar to Esso's, and permits individual ships to load at a rate of 30,000 to 40,000 barrels per hour by gravity flow. The three separate lines from the tank farm permit three ships at a time to maintain this loading rate.

Like Marsa el Brega, Es Sider has three submarine berths. All of them are in more than sixty feet of water and can accommodate tankers up to 100,000 tons. Berths one and three are approximately two kilometers from shore, while berth two is at 1500 meters. All three are oriented true north, a compromise heading between the seasonal winds, which are usually west of north in winter and east of north in summer.

While less exposed to heavy storms and swells than Marsa el Brega, Es Sider has also been closed for hundreds of hours each year because of inclement weather. Here also a technological solution has been sought in the form of a bow mooring device. Based on a design tested by Shell in several Asian and Persian Gulf ports the Es Sider mono-mooring, which was built in the Netherlands, is a buoy rather than a fixed pylon like Esso's. Three flexible sixteen-inch hoses float to the ship's side for loading oil, and they are free to swivel around the buoy. The mono-mooring is far from shore at three and a half kilometers, but it floats in eighty feet of water and can accommodate enormous tankers of more than 140,000 deadweight tons. It came into service in April of 1965 and has been under study and development since. Of a much simpler design than the rigid mooring at Marsa el Brega, the device nevertheless costs about £ 100,000 more than the standard sea berth. Its value has been proved in heavy weather, although the floating hoses are hard to handle and maintain in the choppy Mediterranean seas.

The new port of Ras Lanuf has not yet achieved rates of export comparable to those of the other two, although the big Amal field, initially producing in the spring of 1966, may raise the figures dramatically when it is fully developed. Ras Lanuf rates a superlative in the size of its storage tanks, however. At 500,000 barrels each, they are the biggest in Libya and among the biggest in the world. Three were in use at the end of 1965, with three more under construction for the Amal oil. Holding ten days' production at December 1965 rates, Ras Lanuf's tankage is already the most generous of the three ports. Sitting on a scarp with an average altitude of ninety-nine meters, the tank farm here is also the highest in Libya, though it is the farthest from shore at nine kilometers. Nevertheless, Mobil achieves a better rate of gravity flow than its competitors with the higher hydraulic pressure generated from the tank farm. With the oil passing through a forty-eight-inch line to the meter bank (a second such line was under construction in the spring of 1966) and then dividing into forty-inch lines to the sea berths, Ras Lanuf can load a tanker at 60,000 barrels per hour with gravity flow, a rate that few tankers today can handle.

With regard to the sea berths themselves, Mobil has taken a cautious attitude. Rather than join the sometimes costly pioneering effort to develop a bow mooring, the company has installed two submarine berths (a third to be added in 1966) in seventy feet of water, both less than two kilometers from shore and capable of receiving supertankers up to 130,000 deadweight tons. On the advice of the marine superintendent, who had benefited from three years experience in the winds and seas of Es Sider, berth one is oriented N. 23^0 E. and berth two N. 30^0 W. (330^0 True). The east of north heading is the only one in the Gulf of Sirte and is therefore more particularly on trial; its benefits are felt most often in the summer months. Mobil has now decided to experiment with a dual heading on this berth, providing a shift of orientation to meet the seasonal change in winds.

Utilities and Roads

In view of the generally poor quality of ground water supplies in the Sirtica, it seemed probable that water purification plants would be required in all three ports. At Marsa el Brega, however, Esso found three animal drinking wells with relatively sweet water; pump tests revealed that the yield of the wells was small. Rather than risk excessive drawdown which would encourage contamination by sea water, Esso decided to supply all of its own needs from the beginning with a salt water distillation plant. The three wells on Esso's leased land have been relocated close to the security fence, where they are still accessible to Libyan herdsmen.

Marsa el Brega's water supply has developed in three stages. Originally the port depended on a small 8000 gallon-per-day distillation unit incorporated in the electric power plant. A second unit of 50,000 gallons-per-day capacity is included in the refinery and became available in the spring of 1963. In September of 1965 Marsa el Brega inaugurated the largest distillation plant in Libya, a £. 1.7 million thirteen-stage unit capable of producing 200,000 gallons per day. The port now has enough water for its growing population and even for landscaping, but the distillation plant's capacity will have to be further expanded to meet the needs of the forthcoming natural gas project. All of the port's distillation plants run on crude oil, cleaned first in a centrifuge.

Es Sider's water is produced in two flash distillation units that use heat recircuited from the electric power plant. Each unit is capable of 50,000 gallons per day, but normally only one is used at a rate of 30,000 to 40,000 gallons per day. In the spring of 1966 steam boilers were added to provide additional heat, necessary to run the distillation units when the electric power load is low. The seaweed in Es Sider's harbor has posed a maintenance problem for the plant; the sea water intake filter has sometimes become clogged with the fine, confetti-like substance so well known on the North African coast, necessitating long shutdowns for repair. A problem-free intake design and location have not yet been found, and only the dredging of the harbor keeps the intake clean, with frequent filter changes sometimes being required.

At Ras Lanuf the two distillation units are capable of producing 42,000 gallons of water per day, each powered by its own diesel engine. The possibility of running these units on crude oil was vetoed by the manufacturer of the engines, who judged that Mobil's Hofra field produced oil with a sulfur content high enough to be corrosive. Conscious again of Oasis' experience, Mobil located the intake for its sea water lines at 500 meters from the coast in deep water. Here the only problem thus far has been to design the filter with a large enough mesh to prevent the growth of algae inside the strainer, and this problem appears now to be solved.

The electric powerplants at all three terminals use crude oil for fuel. Esso has two barge-mounted steam turbine generators that supply 25,000 kilowatts, designed to serve the Raguba and Zelten camps as well as Marsa el Brega. Generated at 13,800 volts, the current is stepped up to 138,000 volts for distribution to the oil fields by high tension lines. As demands on the system increased, a supplementary 15,000 kilowatt plant was installed at Zelten in the fall of 1965. Oasis and Mobil have no electric power lines linking their têrminals and their oil fields; the plants at Es Sider and Ras Lanuf are therefore much smaller. Oasis employs three gas turbine generators capable of 1000 kilowatts apiece; one unit is usually enough to handle the load. The crude oil is desalted before use, but some difficulty has been experienced in lubricating the high speed fuel pumps necessary to run the gas turbines. Mobil uses three big diesel generators (a fourth to be added in 1966) of 500-kilowatts capacity each. The engines are started and stopped on diesel, then run on crude when the load builds up. The manufacturer of these engines has qualified his guarantee with reservations as to the content of sulfur in the crude oil, and for several months Mobil used diesel fuel only, until the proportion of high-sulfur Hofra oil was reduced in the total production.

The three terminals have been subject to an unusual geographic problem in the maintenance of their power lines. The standard system of stringing lines, in which insulators protect them from grounding at the poles in damp weather, has not proved completely satisfactory in the Sirtica. Particularly in the months of May and June the combination of humidity, salt, lime and sand, most notable in the early morning hours, can form a conducting track across the insulators, creating a short circuit in the distribution system. Esso, having experienced similar problems in the Persian Gulf, placed its power distribution system for the port of Marsa el Brega underground. The high tension lines running more than 170 kilometers inland were, however, subject to the same hazard. Esso meets this problem with the use of two trucks which patrol the lines, daily, spraying fresh water on the insulators. Even with this precaution some outages have been recorded, and the new power plant at Zelten was built in part as an insurance measure in case of failure. Oasis, with a sturdy surface system of the standard type, has been reluctantly forced into the decision to bury its lines. Mobil, again profiting from the experience of the other companies, employs a different kind of surface system incorporating a bunched, unbroken cable wrapped in rubber insulation running from the tank farm to the port. At the tank farm, however, where it was not possible to use a single, unjointed cable, the standard surface system was tried, but hazards proved severe enough to effect a quick decision to go underground.

With regard to roads and airports, the companies found that the Gulf of Sirte provides good working conditions for both. Flat land for airfields is abundantly available near all three sites; coating with crude petroleum helps to hold down the dust. Oasis and Esso have both purchased large twin-engined craft for company use, indicating the importance which they attach to air transportation in their field networks; and the Kingdom of Libya Airlines began using the Marsa el Brega landing strip, which is asphalted, in the summer of 1966.

Esso has also built an extensive system of asphalt roads both within Marsa el Brega and leading to its major oil fields. While there has been difficulty in finding good quality aggregate and the cost of maintenance has been high, the roads are among the best in Libya. Trucks and Land Rovers heading for camps of competitive companies often drive far out of their way in order to utilize the Esso roads. The asphalt berth at Marsa el Brega has been the source of the bitumen, and it is probable that this berth will also provide asphalt for the rebuilding of the coast road. Oasis has a few bitumenized roads in Es Sider, but its inland roads are simply coated with crude petroleum. Mobil has thusfar constructed only graded tracks to provide access in and out of its port.

Housing and Industrial Quarters

Since all of the terminals were to develop on sites remote from sources of food, labor and recreation, the three companies were agreed on opening their ports as camps. Trailers were the first living quarters in all cases, and, according to the same practices used in oil field camps, the companies provided transportation for their employees' vacations at home.[8]

Oasis and Mobil have continued to operate their ports as camps, and there appears to be no impending change in decision on this matter. Early in its history Es Sider had four bungalows (for families of the top staff members) which were later altered into bachelor housing. In the summer of 1964 Oasis began construction of permanent residential quarters for all of the employees at Es Sider. Planning for a payroll of 290, including fifty-five expatriate staff, the company settled on prefabricated housing of French design, one plan for staff and another for laborers. Local aggregate, beach sand and salt water were mixed with Greek cement and formed into reinforced concrete slabs at Es Sider, then erected on site. Included in the new housing complex are two recreational halls, a library, tennis court and central mess for staff and laborers. Prefabricated slabs from Es Sider were also transported to Oasis' Gialo field in Concession 59 to provide a similar camp there. Expected economies in the prefabricated construction were not realized, however, because of the limitations in the quality of the concrete due to the use of sea water and local limey aggregate. Oasis found it necessary to brace some buildings with steel, and they abandoned plans to use the same construction for their camp at Waha.

Mobil's new housing layout is similar to Oasis'. Using concrete blocks made from local materials, the houses are designed to accommodate thirty-three staff and 150 non-staff employees, each group in its own quarters. A special corrosion and abrasion resistant paint from Mobil chemical laboratories protects the building from the destructive action of lime and sand.[9] Mobil's residential complex includes two tennis courts, a recreational center, and a Muslim prayer area. The locally-formed concrete blocks are also limited in their strength capa-

8. Article 13d, Labor Law of 22 November, 1962.

9. The corrosive action of lime and sand is more penetrating in the Sirtica ports than in Tripoli or Benghazi. Examination of a one-or two-year-old Volkswagen from Marsa el Brega, for example, where the problem is most severe. invariably reveals extensive damage to the paint.

bility, but careful inspection has made their use practicable. Both Mobil's and Oasis' residence complexes were completed late in 1965. Service and construction contractors do not share in this housing but continue to live in trailer camps, tents or temporary housing.

Marsa el Brega, a more complete installation from the beginning, is the first of the terminals to become a residential community. As Esso's commitment in Libya became stronger, management decided to put top supervisory personnel at the scene of action on a full-time basis. Esso called on a Greek consultant to make a series of studies of the factors involved in expanding Marsa el Brega into a town including both Libyan and American families. The consultant stressed the high cost of maintaining people at Brega and the lack of hinterland for the community and Esso has therefore planned the expansion one step at a time. The twenty-seven bachelor units constructed in 1963 on low ground south of the harbor were backed up with 115 family homes built in 1965, enough to serve the staff, including several Libyans, of the expected maximum of 1000 Esso employees in the terminal. Esso designed a Mediterranean-type house with a high wall protecting yards from the wind-blown sand. Each house is centrally air conditioned. The houses are constructed on a surface of limey sand, which is completely unsuitable for growing grasses or flowers. Esso has met this problem by installing concrete flower boxes and by replacing the sand in the front yard with a reasonable soil, originally imported from El Maqrun, 150 kilometers away. An Esso staff member later found some soil in the Brega concession with acceptable levels of alkalinity, and this has been utilized since, at a considerable saving in transport costs.

Landscaping of the community and port of Marsa el Brega is now receiving considerable attention. 3000 eucalyptus trees have been planted in the sand dune that borders the east of the residential area, and there will be 1800 more planted. Each tree is initially planted in an individual can. Rows of eucalyptus and acacia are utilized to form a forest belt, and tamarisk has been planted along the airport road in very alkaline soil. Road intersections are to be beautified with shrubs and flowers. The blasting action of wind and sand, however, have taken their toll in the initial efforts; only the tamarisk has withstood the conditions effectively. An Australian consultant has been given a contract to form a scientific program of landscape development for Marsa el Brega, for the physical problems apparently require full-time study to achieve an effective solution.

The community of Marsa el Brega is still limited to Esso staff members, but it already has a school, market, barber and hairdresser, theater and bowling alley (under construction in the spring of 1966) and tennis courts. There is a nine-hole golf course and a go-kart race track, where the speed record is 59.4 miles per hour. Outside Esso's compound are several camps for service contractors; some of these are now taking on a more permanent appearance with the construction of limestone block houses. With the forthcoming natural gas project committing Esso to deliver 345 million cubic feet per day to Spain and Italy over a period of twenty years from November 1968, the port's importance will be multiplied. The pressures to expand the population of the community will be commensurate with this growth.

While the three ports differ greatly in their residential areas, they all have two-story office and control buildings similar in concept. Oasis' is particularly well sited, standing on a ridge above the port where all four mooring berths are clearly visible. Panoramic windows and a balcony in the upstairs control center take full advantage of the excellent location. Mobil and Esso were a little less fortunate in their control centers. While Mobil's building is also well located on a ridge, the office building, designed in Texas, provides only shoulder-height windows, partly to achieve economies in air conditioning. The desirable view can only be secured at close proximity to the windowsill and not, for example, from the radiotelephone unit. Esso's office building is on low ground behind a seven-meter mound. The possibility of bulldozing this obstacle out of the way was vetoed by the discovery of some ancient tombs within the mound, in which the Libyan Department of Antiquities became interested. Esso's marine officers must peer from one window to another in order to check ships as they berth and load. A proposal has been made for a new control center on the peninsula, offering an unobstructed vista of the sea berths.

A big problem in all of the ports, especially when the ghiblis blow, is the intrusion of sand into machinery, typewriters, food, correspondence, electronic equipment and almost everything else, whether hidden or exposed. Esso takes one precaution not employed by the other companies. All of its offices, control rooms and sub-stations are air conditioned under mild pressurization in order to reduce the intake of sand into the buildings.

Conclusions

Libya is the first country in history to have acquired three operating petroleum ports within a period of ten years from the enactment of its petroleum law. By the end of 1966 a fourth port, British Petroleum's Marsa Hariga in Tobruk harbor, will be operative, and within a few years a fifth port may appear in the west, somewhere near Tripoli, as an outlet for the smaller oil fields which have been discovered in Zones I and IV. Given the nature of the petroleum law and the introduction of fifteen new companies into the concession grants of February 1966, it is conceivable that more ports will be added in the Gulf of Sirte, especially if a major field is discovered by a new company. Minor oil discoveries will probably be channeled through one of the existing ports, however, as has been the case with Phillips' Umm Farud and Pan American's Khuff fields, now producing through Ras Lanuf. As of 1966, it should be noted, only the Mobil-Gelsenberg-Amoseas pipeline network has surplus capacity available for export of oil from the Sirtica basin.

The three existing terminals will always remain interesting because of their pioneering status. Esso chose a site that permitted a multiple-function port but compromised with marine conditions. The bow mooring has provided only a partial solution, so Esso's exports have invariably dropped notably during the winter months, usually February and

March. Oasis, with more limited ambitions for Es Sider, attempted to utilize local materials and simple methods of construction in so far as practicable. The company also had to compromise—the simplest method often proved ill adapted to geographical conditions and required a follow-up decision involving some unexpected capital expense. Thus the company buttressed its breakwater with concrete tetrahedrons, purchased a suction dredge for the harbor, reinforced its prefabricated housing with steel, and buried its electric transmission lines. Es Sider's increasing sophistication is illustrated by its attractive new living quarters and its growing exports, taking over the number one spot from Marsa el Brega during the winter of 1965-66. Mobil started with a simple formula but carefully studied techniques, particularly in regard to harbor construction. Mobil acquired, though it was third choice, what is in some ways the best of the three sites, particularly with regard to gravity flow of petroleum. Mobil profited well from its competitors' experiences, meeting the problems with ingenuity, but it still faced a few small surprises—the tank farm power lines had to go underground, and control personnel were inconvenienced with an inappropriately small window designed in Texas.

In a final evaluation Libya's three ports can be compared with La Skhirra in Tunisia, operated by the French Trans Saharan Pipeline Company (TRAPSA) and drawing from the Edjeleh and Zarzaitine oil fields in Algeria. Opened in September of 1960, La Skhirra still exports at less than half the rate of Marsa el Brega or Es Sider. The site has a hill only thirty meters in height, making auxiliary pumps necessary for most loading operations. But La Skhirra enjoys many advantages not found in the Libyan ports. Its site was dictated by marine conditions. The company found a location with an effectively sheltered berthing area at La Skhirra and decided that it was worth sixty kilometers of pipeline to locate here rather than at the closer but more exposed port of Zarzis, farther south in Tunisia. TRAPSA built a pier one and a half kilometers in length to the berthing area, allowing a car to drive right up to a ship as it moored and facilitating the mooring and loading processes. The naturally-protected berthing area in this section of the Gulf of Gabes, better than anything found in the Gulf of Sirte, restricts waves to about two meters in height even in heavy storms, as compared to about eight meters for the Libyan ports. La Skhirra has therefore been able to load tankers originally bound for the Gulf of Sirte but turned back by heavy weather. The TRAPSA port is also able to draw on the extensive facilities of the city of Sfax, only eight kilometers away, where most of the labor force is housed and most of the mechanical repairs of tugs and vehicles are performed.

Two aspects of the development of La Skhirra merit special attention. One is the system provided for deballasting, incorporating basins on shore which receive all the ballast from incoming tankers and recover the petroleum, preventing its being dumped at sea. Beaches in the Gulf of Gabes are thus kept completely free of accumulations of tar. The well-known tar on some Libyan beaches is due chiefly, it should be noted, to the presence of an authorized dumping ground for dirty ballast about 160 kilometers from the Libyan coast; the prevailing winds carry the oil southward onto the sands. Much of the dumping is performed by tankers headed for the Suez Canal rather than for Libyan ports.

A second remarkable feature of La Skhirra is its landscapping. While the vegetation of the coastal area in the Gulf of Gabes is a steppe only slightly richer than that in Sirtica and while the water problems are similar, the Tunisian area is swept far less by wind and sand. Hence TRAPSA's energetic efforts at beautification have been richly rewarded. The 10,000 eucalyptus, acacia and tamarisk have all done well, and flowers and shrubs brighten the industrial and residential areas. Only fifteen families live permanently in La Skhirra, but they consider the esthetics important to their morale.

Comparison appears to confirm that the Gulf of Sirte offers unusually difficult conditions for the establishment of petroleum ports. The companies have certainly acted decisively to meet these conditions, but perhaps they have not conquered them, particularly with regard to the Mediterranean storms and the destructive ghiblis. Occupance of this land, even in the case of the growing community of Marsa el Brega, is governed solely by the pull of remote economics, so one cannot be sure of the permanence of the three installations. Fishing is a possible supplementary activity to help support the populations, though up to now only one company engages a single fisherman to aid in the food supply. With faith in the vastness of Libyan oil reserves and the constantly advancing technology which has created these ports in a few short years, one can predict a long future for them. They all may benefit one day from the development of a cheap process to purify sea water, but this is probably still many years away.

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