1 Introduction

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Humankind needs to move fluids from place to place. Some fluids have to be moved in huge quantities and over long distances: water, oil, natural gas, and carbon dioxide are examples. Other fluids have to be moved in smaller quantities or over shorter distances: steam, ethylene, blood, milk, wine, helium, mercury, nitroglycerin, and petrochemicals are examples.

There are essentially three ways of moving fluids. The first is to pour the fluid into a tank, move the filled tank to where the fluid is needed, and empty the tank. The essential components of that method are a tank that can be moved and a way of filling and emptying it. The second way is to construct a pipe from where the fluid is to where the fluid needs to be and to pump the fluid along the pipe. The third method, sometimes used in combination with the other two, is to transform the fluid into a solid or into another fluid that can be transported easily.

The tank option is flexible and often has lower capital costs but higher operating costs. This option invariably is used for small volumes of high-value fluids such as mercury, wine, blood, and helium. The tank protects the fluid against contamination from outside. The risk that the transported fluid might escape and damage the environment depends on the integrity of the tank. The method is used widely to transport oil and liquefied natural gas (an example of the transformation option) by sea because of the flexibility it allows. The same VLCC same very large crude carrier can transport oil from the Middle East to Japan on one voyage and oil from Alaska to California on the next voyage; and during the voyages, the cargo can be sold and resold, diverted to a different destination, and partly offloaded at yet another location. Oil is transported over long distances by rail where no pipelines exist. For example, oil from central Russia goes to the Russian Far East by rail, and oil from the Wytch Farm field in southern England was exported by rail until production increased to the level that justified building a pipeline.

The pipeline option is relatively inflexible by comparison. A pipeline is a fixed asset with large capital costs. Once the pipeline is in place, though, the operation and maintenance costs are relatively small; and the pipeline has an operating life of 40 years or more. A land pipeline may be vulnerable to damage by war or terrorist attack or to interruption of service by political interference from one of the countries it crosses. It is this factor that has limited the application of pipelines to carry oil from the Middle East to Europe and so far has prevented the construction of a gas pipeline from Nigeria to Europe. Pipeline transportation consumes little energy. The most dramatic example is the comparison between, on the one hand, pipeline transportation of natural gas and, on the other hand, liquefaction followed by sea transportation by tanker followed by regasification. Even over a long distance, operation of a pipeline uses no more than 10% of the energy content of the gas, whereas the liquefied gas option uses more than 30%.

This book is about pipelines under water, which are used in various contexts. More and more oil and gas are being produced from fields that lie under the sea. The product has to be carried to shore; and that is usually, though not always, done by pipeline. Intrafield pipelines carry oil and gas from wellheads and manifolds to platforms and from one manifold to another. Sometimes gas from one field is transported to another field to be injected to maintain reservoir pressure. Then treated seawater is injected to displace the oil, and occasionally carbon dioxide is separated from the gas and reinjected, as occurs in the Sleipner field in the North Sea and in the future in the Natuna field off Indonesia.

Many pipelines that are primarily on land also have to cross seas, straits between islands, and river estuaries. Chapter two describes two examples, the first a pipeline to Vancouver Island in western Canada and the second a pipeline from Algeria to Spain. Several ambitious long distance projects currently under study include crossings of this type: examples are the pipeline from Papua New Guinea to Australia and the pipeline from Qatar to India and Pakistan.

These examples refer to gas and oil, but transportation of water is also important. It has been argued that, as world population grows, water will be a greater problem than energy and that it will become a major source of conflict. Several projects are examining long distance water pipelines, which are necessarily very large if they are to be useful.

There is growing concern about carbon dioxide released into the atmosphere by burning fossil fuels and about its effect on the global climate. One mitigation option is to capture carbon dioxide at large point sources such as power plants and cement plants, and then to store it in the deep ocean or in geological formations under the ocean.[1] If these schemes come to pass, very large quantities of carbon dioxide will have to be handled for the beneficial impact on climate is to be significant because the present rate of release is 6 billion tonnes a year. It follows that any storage scheme that involves the oceans necessarily will generate a large additional demand for pipelines.

It is also necessary to dispose of water. Outfalls carry treated sewage and storm water into the seas and rivers. Coastal power stations draw in cooling from intakes and dispose of warmer water from outfalls. Outfalls have also been used to dispose of materials such as mine tailings and raw sewage, but there are often substantial environmental and legal objections to these disposal options, making them less and less often appropriate.

Section 1.2 presents the book’s organization. Section 1.3 is a brief historical introduction to pipelines.

1.2 How This Book is Organized

The chapter themes relate to areas of knowledge, which broadly match groups of decisions that a pipeline engineer has to make.

The first task of the pipeline system designer is to choose the pipeline route. Sometimes this task is straightforward: If the seabed is smooth and featureless, a straight line between the end points is the shortest and most economical route. More often, there are various obstructions and interferences that compel the designer to select a more complex route. The factors involved may be physical, environmental, political, or related to other human uses of the seabed.

The designer then has to consider materials. Many pipelines are made from low-alloy carbon steel, which is a robust and inexpensive material. However, frequently the fluid in the pipe corrodes carbon steel too rapidly for its use to be acceptable. The designer then has to consider a corrosion-resistant alloy, a flexible, or a composite. Usually, each of these alternatives is more expensive than a low-alloy carbon steel; and an alternate material may present other problems such as difficulty in making connections, but it may lend itself to an economical overall solution. The pipes have to be joined together, and careful decisions have to be made if the pipes are to be welded.

The next task is to decide on the diameter of the pipeline. That decision primarily rests on the hydraulics. If the diameter is too small, the pressure drop between the ends will be excessively large, but if the diameter is too large the cost will be unnecessarily great; and undesirable flow modes may occur in two-phase flow. Detailed decisions about the composition and specification of the material involve many interacting factors of corrosion resistance, weldability, strength, fracture toughness, and cost.

The next choice is the wall thickness of the pipeline. This is primarily an issue of structural engineering in which the designer has to ensure that the pipe is strong enough to resist many kinds of loading, among them internal pressure, external pressure, bending and fatigue during construction, concentrated loads, and impact.

Almost all underwater pipelines have an external coating to protect them against corrosion, complemented by a cathodic protection system that prevents external corrosion if the coating is damaged. Many pipelines have additional concrete weight coating to provide stability against waves and currents and to give the anti-corrosion coating protection against mechanical damage. Some pipelines have one or more additional layers of thermal insulation, required to maintain the fluid contents at a high temperature. Still other pipelines have internal coatings as corrosion protection or to provide a smooth inner surface to reduce the resistance to flow.

A pipeline must be constructible. The designer needs to know the limitations of the available construction systems, and he has to design the pipeline so that it can be built safely and economically. Many pipelines are trenched or buried in order to provide shelter against hydrodynamic forces, to protect them against mechanical damage, or to provide thermal insulation and resistance to upheaval buckling.

Pipelines do not always rest continuously in contact with the seabed, and there may be spans in which the pipeline bridges across low points in the profile. Spans can give rise to various structural problems and may need to be corrected. Uneven seabed profiles can also initiate upheaval buckling in which the pipeline arches above the bottom. That situation also has to be guarded against and if necessary corrected. Pipelines can also buckle sideways.

Pipelines in service may be subject to damage by chemical and microbiological corrosion. The designer needs to know how to suppress corrosion as far as possible and how to allow for it in the choice of wall thickness. The operator needs to know what operating practices are likely to minimize corrosion and how to monitor it.

A pipeline is at risk of damage, and repairs may become necessary. A chapter on risk, accidents, and repairs examines the general principles that apply to repair and presents case studies of incidents that have required intervention and the repair techniques used in each instance. Ultimately, a pipeline has to be decommissioned when its operating life has ended or when it is no longer needed. Decommissioning is an evolving subject of which there is little experience as yet, but it is an increasing concern to operators, to regulatory authorities, and to the wider community. It engages various factors, among them national and international law, environmental protection, the safety of other seabed users, and engineering.

Finally, neither design nor construction is a mature or dead technology. New ideas are coming forward all the time, There are new understandings that overturn established notions and new techniques that make it possible to build pipelines more cheaply, more quickly, and more safely than ever before. It is famously difficult to foresee the future, but the final chapter discusses some promising ideas.

References are indicated in the text by superscripts and are listed at the end of each chapter.

1.3 Historical Background

The oldest marine pipelines were outfalls, which have been used since the nineteenth century when it was realized that simply dumping sewage into rivers and onto beaches created harmful and unpleasant pollution.[2] The earliest marine pipelines for oil were short loading and unloading lines, generally constructed by building them on shore and winching them into the water. This remains the usual way of constructing pipelines between the shore and offshore loading points and of constructing river and estuary crossings. Alternative versions of the pull technique for installation are various kinds of tow, where the pipe is built on shore then towed or dragged to its final location.

The offshore petroleum industry is relatively recent historically. The first well out of sight of land was drilled in the Gulf of Mexico in 1947 at Kerr McGee's Ship Shoal block 32, 17 km from shore and in 6 m of water. The earliest petroleum pipelines date from before 1947 and were set in very shallow water in the Gulf of Maracaibo and the Caspian Sea off Azerbaijan. In time, there came to be a need for pipelines over longer distances. One urgent need arose during the Second World War when the Allies realized that they would have to invade the continent of Europe and that that the ports would have been destroyed during the invasion. The Allies also knew that an invading army would require vast quantities of gasoline. The military authorities called in Anglo-Iranian, the forerunner of British Petroleum, and asked the company if it would be possible to lay pipelines from England to France across the English Channel. Two kinds of pipeline were devised for the project, which was called Pipe Line Under The Ocean (PLUTO). One was rather like a submarine cable with no central core, formed from a lead tube wound with armor layers of steel tape and plastic. The other was a welded steel pipe with no anti-corrosion coating. Among the impressive aspects of the project was that the first trials were carried out just a week after the first meeting, something that few oil companies could manage nowadays.

Conventional small cable ships laid the cable-like pipe. The steel pipe was made up in great lengths and then wound onto floating reels (conundrums). Tugs towed the drums across the Channel, unwinding the pipe as they went. By this means, a pipe could be laid from the Isle of Wight to the Cotentin Peninsula in ten hours (and that, too, could not be accomplished now). It is fair to add that the value of PLUTO is disputed. Some authors argue that it had little impact in comparison to tanker transportation into newly constructed harbors and imply that it was a waste of effort, but others are more positive.[3,4]

Reel ship technology was picked up and developed in the Gulf of Mexico and led to the construction of a series of reel barges and reel ships, which continue to earn a significant share of the pipelaying market.

A different technology was developed in parallel. It is related to land pipeline construction, where lengths of pipe are laid out along the right-of-way, welded together length by length, and progressively lowered into a trench. The lay barge system consists essentially of a barge with a fore-and-aft line of rollers (firing line) along which are spaced a number of welding stations. Lengths of pipe are brought to the bow of the barge and welded to the end of the length that has already been completed. The barge moves forward one length at a time. Successive weld passes at the stations complete the welds. The pipe leaves the stern of the barge over a curved support called a stinger, and then lifts off the stinger and curves downward until it reaches the bottom.

Another development pulled pipelines in various ways, sometimes along the seabed, sometimes just above the seabed, and sometimes at the sea surface supported by pontoons. This group pf methods is widely used for shore crossings but can be applied in deeper water and to longer pipelines.

Lay barge technology was developed in the Gulf of Mexico, and then brought to the North Sea and the Arabian Gulf. The earliest barges had simple rectangular box-like hulls, but later barges had ship-form hulls. Some barges applied the semi-submersible principle, which reduces motion in a seaway by setting most of the buoyancy well below the waterline, with the barge topsides supported on comparatively slender surface-piercing columns. Different combinations of larger hulls and semi-submersible hull forms made it possible to increase lay productivity in exposed locations such as the North Sea.

Most marine pipelines are laid by the lay barge method, which has proved itself flexible and versatile. The first barges were positioned by long mooring lines stretching from winches to anchors on the seabed; but many recent barges are dynamically positioned by thrusters, which liberate them from the potential problems inherent in complex mooring systems.

Early pipelines were all within water depths accessible to divers, and many construction operations were carried out with diver help, particularly when connections were needed. The demands of offshore petroleum production have taken the requirement to construct pipelines far beyond the maximum depth that divers can reach, which is about 300 m; and the past 25 years have seen an enormous development of diverless operations. Depths of 1000 m are now routine. A pipeline across the Black Sea in depths down to 2200 m has been completed and is in operation, and several other projects in depths between 1500 and 2500 m are now in progress.

References

[1] Palmer, A.C. and B. Ormerod. “Global Warming: the Ocean Solution.” 1997. ***Science and Public Affairs***. Autumn, 49–51.

[2] Grace, R.A. (1978). ***Marine Pipeline Systems***. Englewood Cliffs, NJ: Prentice-Hall.

[3] Yergin, D. (1991). ***The Prize: The Epic Quest for Oil, Money and Power.*** New York: Simon & Schuster.

[4] Searle, A. (1995). PLUTO: ***Pipe-Line Under The Ocean, the Definitive Story.*** Shanklin, England: Shanklin