Subsea Pipeline Engineering
2nd Edition

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Preface

Submarine pipelines are the arteries of the oil and gas industry, important in engineering practice and full of excitement and interest, though at first sight less spectacular than platforms and floating production systems. The technology has advanced dramatically. Projects that were dreams 20 years ago are now becoming reality.

I came into this field by lucky chance. I was a university lecturer in Cambridge, and in the summer of 1970, I was invited to spend the summer at Brown University, where I had completed my PhD five years earlier. The Alaska pipeline was in the news. Former colleagues in the Division of Engineering remembered that I had worked on permafrost as a sideline to my PhD, and they had some money for research on geotechnical aspects of environmental problems. They told me that if I could oversee the research, they could support me for the summer. I was keen to go and networked through a colleague in Cambridge to locate the people in British Petroleum (BP) in London who were working on the problem. I told that them that I was not looking for money but was looking for an interesting problem. Impressed by this refreshingly naive approach, they gave me a problem to do with differential settlement on thawing permafrost; I researched that topic and was taken to talk to the pipeline team in Houston.

A year later, BP called me again and said that there were questions about a planned North Sea pipeline, Forties, the first large-diameter line in what was then thought of as deep water, 125-m deep.

"That sounds interesting," I said, "but I don't know anything about underwater pipelines."

"We think that's an advantage," they replied. "You'll bring a fresh mind to it. Come and see us tomorrow."

That phone call changed my life. Over the next few years, I worked on a number of problems, among them pipelaying mechanics, buckle propagation, interaction with sandwaves, modeling, and surface tie-in. Since then, most of my work has been in pipelines. In 1975 I went to work for the leading consultant in underwater pipelines, R.J. Brown and Associates, and worked on projects in Arctic Canada, the North Sea, and the Middle East. It was in that period that I first met my friend and co-author Roger King, and later we worked together at University of Manchester Institute of Science and Technology (UMIST). Ten years later, I started my own consulting company, Andrew Palmer and Associates, and we worked on exciting projects in every continent.

There are many books, and each one needs a reason for its existence. Our justification for the present book is that we believe—and, more importantly, others have confirmed to us—that there is no other book that covers the same ground, though there are excellent books on land pipelines and on outfalls. There are many technical papers, but most of them are in the conference literature and are not readily accessible. Roger and I thought it useful to bring together in one volume the state of the art in a form that would be accessible to the nonspecialist and at the same time would provide references to topics that we did not have space to follow up in detail. We are primarily concerned with oil and gas pipelines that operate at relatively high pressures and sometimes in very deep water, but most of the ideas are equally applicable to lines that carry water and sewage.

No doubt there are mistakes. They are our responsibility, and we hope that readers will tell us about them.

The authors have taken this opportunity to remove outdated material, correct mistakes, and reflect new developments. They welcome comments and suggestions.

Singapore and Manchester
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1 Introduction

1.1 Motivation

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 basic 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, then pump the fluid along the pipe. The third way, sometimes used in combination with the other two, is to transform the fluid into a solid or another fluid that can be transported more easily.

2.5 Case Studies

Two case studies exemplify the interaction among different factors. British Columbia Hydro and Power Authority (BC Hydro) wished to build a pipeline across the Strait of Georgia, from the Fraser Delta area south of Vancouver to a landing on Vancouver Island. The project is described in greater detail by Park.[10] The plan was to construct two lines to obtain additional security, and to make the diameters 273.05 mm OD (outside diameter; nominal 10-inch), chosen to match the expected demand. Figure 2–1 is a sketch map.

The political boundary between Canada and the United States at 49° N lies just south of the delta, cuts across the Point Roberts peninsula, and extends westward to the middle of the Strait of Georgia. BC Hydro decided early on not to cross that boundary, because to do so would have brought part of the pipeline under the jurisdiction of U.S. federal authorities, as well as numerous state and local authorities, and would make it liable to a challenge in the U.S. legal system.

The land portion of the delta consists of low-lying islands. The delta is fronted by a tidal flat, Roberts Bank, which is mostly dry at low tide and covered by about 1 m of water at high tide. The landward sections of the bank are covered by grasses and seaweeds, and are fish spawning areas, so it was decided to schedule construction to avoid the spawning season. The top of the bank is almost level, but the foreslope on the seaward side is relatively steep.

British Columbia has fewer earthquakes than California to the south or Alaska to the north, but there are occasional large earthquakes. Oscillatory shear stresses induced by an earthquake might liquefy the loose and geologically recent sand and silt sediments of the bank, and parts of the foreslope could then become unstable, liquefy, and slide downhill into deeper water. The risk of liquefaction is least where the gradient of the foreslope is smallest, about mid-way between the South Arm of the Fraser and Canoe Pass, and so it was decided that the pipeline should traverse the foreslope at that point. The route runs straight down the slope, so that if a flowside should occur, the sand would flow along the pipeline rather than across it. The reason for that choice of direction is that a pipeline can withstand very large forces applied along its length but only smaller forces applied across its length.

A plot of toughness against temperature appears as two plateaus linked by a sloping ramp. The toughness of steel, measured as its resistance to sudden impact, is only slightly reduced with reducing temperature from ambient until the upper critical temperature is reached. At and below this temperature, the toughness of the steel declines. Below the lower critical temperature, the impact resistance of the steel remains relatively constant at the lower value. The nonductile transition temperature is the temperature roughly halfway between the two critical temperatures. For high-carbon steels, the transition ramp between the upper and lower shelves is steep, and for low-carbon steels, the ramp is gradual. The plateaus are called the upper and lower *shelves.* The broken surfaces are usually examined after the impact testing. Ductile failures show a rough cup-and-cone appearance, and the ratio of this area to the complete fracture surface is used as a parameter in evaluating the point of changeover from ductile to brittle behavior. For pipeline materials, a typical requirement is 85% ductile fracture at the given test temperature.

The point of transition from ductile to brittle is defined as the nonductile transition temperature (NDTT). This is the temperature at which the fracture surface appears 50% ductile and 50% brittle. One major unresolved problem is that the different test methods and their interpretations give different critical temperatures. It is important that the test method to be used and the test result interpretation are agreed upon by the specifier and material provider.

The NDTT is a function of metal composition and grain size, item thickness, and rate of impact. The slope of the ramp reflects the statistical variation of these properties within the steel. Thick section material has a higher transition temperature than thin metal because the thin material can yield, thus reducing the effective rate of transfer of stress. Slow impact loading allows the material to deform in a plastic manner, reducing the NDTT. Pipeline testing generally uses full thickness specimens of pipe, though thinner samples can be used if the pipe wall thickness is very large, but this variation in testing is subject to negotiation between the purchaser and the pipe producer.

Whereas strength of materials is well understood, toughness is not. Toughness is increased by reducing alloying content and/or decreasing the grain size. However, other factors are important, for example, the degree of segregation of phases within

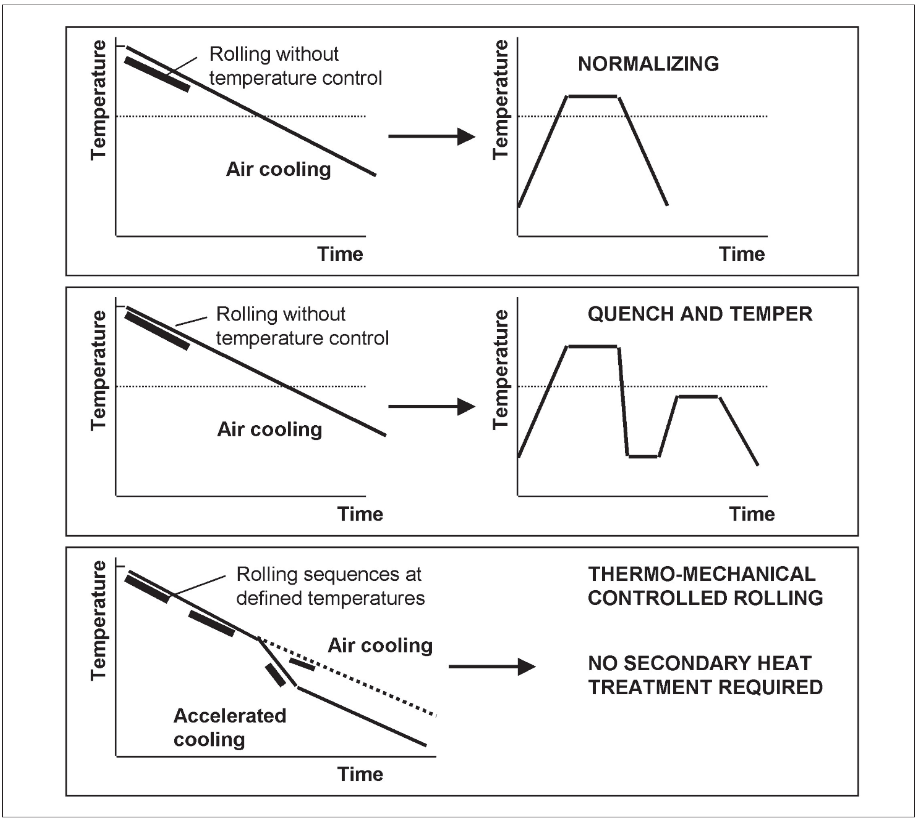

Fig. 3–5. Hot-rolling steel plate and strip production processes

Option 1 of figure 3–6 is the simplest TMCP and is the original controlled-rolling process developed to produce large sheets of high-strength steel for construction of ships and super tankers. The slab is heated to 1,200–1,250°C, and the steel is rolled to the *roughing* stage. The plate is allowed to cool to a temperature where it remains austenitic, but reworking the grains will not recrystallize as a result of the work input during the second phase of rolling. The steel is cooled further until it is on the borderline of the transition zone of austenite to ferrite, and is finished by rerolling at this temperature to form elongated, austenite grains. On further cooling, the steel recrystallizes into fine ferrite and pearlite grains. The energy input in working of the austenite grains at the transition temperature results

4.3 Available Corrosion-Resistant Alloys

4.3.1 Metallurgical structure

The structure of a stainless steel can be determined from the Schaeffler diagram (fig. 4–5). Some alloying elements promote the formation of ferrite (e.g., chromium), while others promote the formation of austenite (e.g., nickel). The diagram in figure 4–5 maps the complete range of stainless steels. The formulas used to determine where an alloy is located on the Schaeffler diagram are listed here:

Chromium equivalent (ferrite forming) =

$$Cr + 2\ Si + 1.5\ Mo + 5\ V + 5.5\ Al + 1.75\ Nb + 1.5\ Ti + 0.75\ W \tag{4.6}$$

Nickel equivalent (austenizing) =

$$Ni + Co + 0.5\ Mn + 0.3\ Cu + 25\ N + 30\ C \tag{4.7}$$

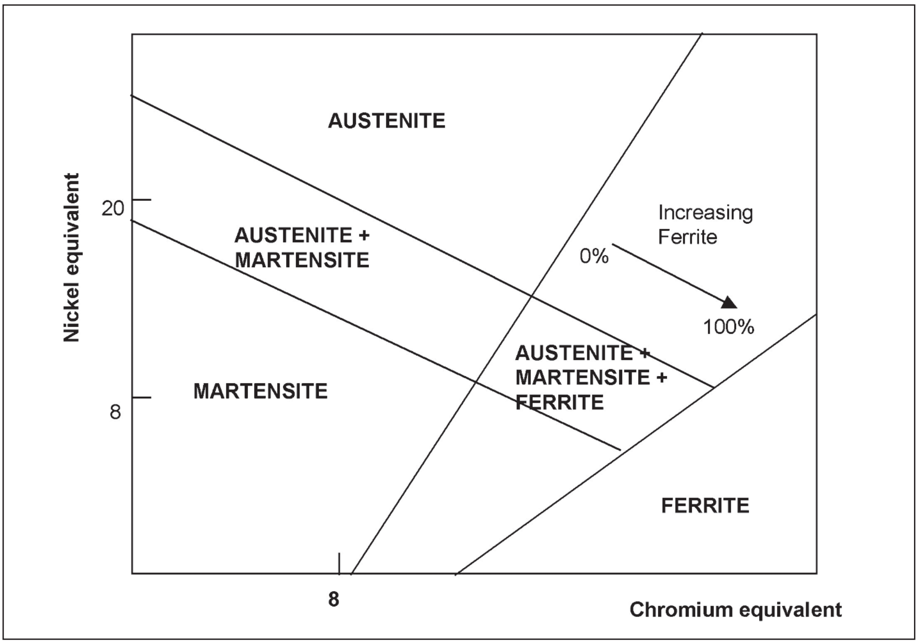

Fig. 4–5. Schaeffler diagram