The Engineering Science of Oil Pipelines

From the Keystone XL pipeline project to spills and leaks in existing lines, pipelines are in the news.
The SMCC has prepared this backgrounder on crude oil and pipeline engineering. If you would like to speak to an expert about this topic, call us at **613-249-8209 or 438-288-3909.**

****NOTE: regulations and practices referred to in this backgrounder are general; specific pipelines may be subject to more specific guidelines.**

What is crude oil?

Crude oil (or "petroleum") forms in the earth's crust by the heating and compression of organic materials over millions of years. It is comprised primarily of hydrocarbons, other organic compounds and small amounts of other components like metals. Crude oil is extracted with wells or strip mines, and refined into petroleum products such as gasoline, diesel, heating oil, solvents and lubricants. Crude oils are classified according to their per unit weight (specific gravity).

Light crude oil has a low density and flows freely at room temperature.
Heavy crude oil does not flow easily at room temperature. Heavy crudes must be blended, or mixed, with condensate (liquids often found in the ground with natural gas) to be shipped by pipeline.
Bitumen is a highly viscous form of heavy crude found in the Alberta Oilsands. In order to meet pipeline viscosity and density guidelines and make it flow through pipes, it is often blended with additives like Naptha. 'Naptha' is any of various volatile, often flammable, liquid hydrocarbon mixtures used chiefly as solvents and diluents. This blend is called dilbit (diluted bitumen).

Oil can also be divided into sweet and sour crudes. "Sweet" crudes contain less than 0.5 per cent sulphur.

How does a pipeline work?

Oil pipelines transport liquid petroleum products from one point to another. There are generally three types of oil pipelines[1]:

1. *Gathering lines*: travel short distances, collect unprocessed oil products from wells and deliver them to oil storage tanks. Pipes range from 4 to

12 inches in diameter. There are more than 250,000 kilometers of these lines in Western Canada (primarily in Alberta).

2. *Feeder lines* move product from oil storage tanks and processing plants to the transmission pipelines. They are generally bigger than gathering lines, but smaller than transmission lines. There are more than 25,000 kilometers of feeder lines in Western Canada.
3. *Transmission lines* can be up to 48 inches in diameter and transport oil and associated products from producing to consuming areas, including across provincial and international boundaries. The oil is piped to refineries where it is refined into petroleum products. There are more than 100,000 kilometers of transmission lines in Canada, roughly 2.5 times around the globe.

See graphic: http://www.cepa.com/pipelines-101/types-of-pipelines/liquids-pipelines

The main features of an oil pipeline are:

- Storage tanks to accumulate oil for injection and to accept deliveries.
- Injection stations: where the product is injected into the pipe.
- Pump stations: located along the line to keep the product moving.
- Intermediate delivery stations: allow product to be delivered to clients along the way.
- Block valve stations: allow a section of the pipeline to be closed for maintenance, or to isolate a leak or spill. These can be operated manually, or remotely.
- Final delivery station: where the remainder of the product is distributed to the client.

How much oil moves through a transmission line?

Approximately 3 million barrels of crude oil travel through Canada's pipeline network every day, enough to fill almost 200 Olympic-sized swimming pools[1].

What causes internal and external corrosion of a pipeline?

Most transmission pipelines are buried in the ground and are made of carbon steel. External corrosion is caused by electrochemical interaction between the pipe and the surrounding environment (soil in the case of buried pipes). The process is similar to the reactions in a battery, where electrons flow between anodic (positive terminal) and cathodic (negative terminal) sites on metals. Operators try to prevent external corrosion by coating the pipe with a corrosion resistant material (such as epoxy) and by applying an external voltage source to keep the pipe cathodic (*cathodic protection*).

Although all pipelines are coated and under cathodic protection, corrosion can still occur. This may occur through a process called cathodic disbondment -- the

loosening of the coating from the pipe. Internal corrosion can also occur, however it usually occurs only when there is significant water content mixed in with the fuel flowing through the pipe. In large transmission pipelines, the NEB requires that oil contain no more than 0.5% water so that the pipe contents are not corrosive. Corrosion inside pipelines usually only occurs in areas where deposits of sludge build up. Sludge is comprised of *sediment and* bacteria that can grow in the small pockets of water. Some sludges are more corrosive than others, and research is currently underway to better understand how to prevent these sludges from forming.

At the temperatures at which crude oil and dilbit (diluted bitumen) are transported through pipelines, heavy crudes are no more corrosive than light crudes. If a particular crude oil is found to be corrosive, a chemical corrosion inhibitor can be injected into the stream. Corrosive components can also be removed. New pipelines have epoxy coatings which are more corrosion-resistant than older pipelines.

What are corrosion pits?

Corrosion pits are very localized corrosion defects, or small ‘pits’ in the metal of the pipe. Pitting corrosion, unchecked, can result in a pipeline leaking. Operators have criteria to assess pits. Canadian codes require pits to be repaired when they reach 80% of the wall thickness. European codes allow up to 85%. In-line inspection tools (known as intelligent pigs - see below) are used to detect pits and/or cracks.

How are pipelines monitored?

Pipelines are required to be monitored by the National Energy Board (below). The pipeline right-of-way is monitored through weekly, bi-weekly or monthly inspection. Pipeline operators may fly over the lines, drive along side where possible, and conduct investigative digs around the line.
Internal inspection of the pipe is generally carried out on a five to ten year basis by high-resolution inspection tools (known as intelligent pigs – see below) that can detect damage.

The operating company controls and monitors activity along the entire pipeline with a Supervisory Control and Data Acquisition (SCADA) system that is active 24 hours a day. The SCADA system collects information about valve function, line pressure, and rate of flow, and is equipped with automatic leak-detection systems and alarms. If the computerized system fails, another system in a different location will come on-line.

What are “intelligent pigs”?

Pipeline operators use in-line inspection tools called “intelligent pigs” (pigs) that

can detect corrosion, determine the size of dents in a pipeline, and determine changes in alignment of the pipeline. The latter can impose a strain in the pipeline that might lead to a leak or a buckle in the pipeline body.

Corrosion detecting pigs use either ultrasonic technology (UT) or electromagnetic technology (MFL). Currently these technologies have roughly equivalent detection ability. MFL can be used for both gas and liquid pipelines. UT pigs have to run in liquid lines. Modern pigs have a high probability of detection (about 90%) and can size defects with around 80% confidence.

A typical high-resolution tool will detect a pit that has a width about 15% of the thickness of the pipe wall. For a pipe wall 10 mm thick, the pit would be the size of a grain of rice. If a pit is
discovered, sized and found not to threaten the pipeline integrity, it can be re-coated with an anti-corrosion sealant and left in the line.

How does the federal government regulate maintenance and/or cleanup?

In Canada, the National Energy Board (NEB) regulates pipelines that cross provincial or international borders, and requires companies to monitor the condition of the pipeline (an integrity management program). The NEB has the authority to enforce compliance with a range of enforcement actions including corrective action plans, Board orders and prosecution through the courts.

Should an NEB-regulated pipeline have a spill, the NEB oversees the company's response to spills and, along with the operator, alerts and coordinates with other organizations or relevant authorities. The pipeline operator is responsible for cleanup and managing any leaks or spills.

The pipeline operator is responsible for reporting the incident to the Transportation Safety Board of Canada (TSB). The company would then implement their emergency response plan, which is required to be on file with the NEB and TSB. Either the TSB or the NEB may investigate the cause and contributing factors of the incident.

What causes leaks and ruptures?

Internal corrosion, external corrosion, external intervention (for example: hit by a truck or back-hoe), soil displacement such as landslides, material defects, and system malfunctions (for example: operating over design pressure) can cause leaks and ruptures.
Based on incidents reported to the National Energy Board, the majority of leaks are related to pump stations and valves, rather than the body of the pipeline. In general, corrosion accounts for about 20% to 30% of pipeline leaks.

How often do leaks and spills occur?

The Transportation and Safety Board of Canada (TSB) records pipeline incident statistics for Canada[2]. The average number of incidents per year between 2006 and 2010 was 53. Roughly nine leaks and spills per year happened along pipelines while on the other 44 occurred in facilities such as compressor or pump stations. These numbers do not include the leaks and spills on pipelines regulated by the provinces that do not cross provincial or national borders.

What are the most active areas of research in pipeline technology?

Research addresses improved pipeline coatings, welding techniques, techniques to increase the toughness of high strength steels, prediction and process optimization for mitigation of internal pitting corrosion, corrosion of pipelines under multi-axial stresses, and microbial-induced corrosion. Since intelligent pigs are the most commonly used inspection tools, tool vendors continually try to improve performance.

[1]Canadian Energy Pipeline Association, September 7, 2011. http://www.cepa.com/pipelines-101/types-of-pipelines
[2] http://www.tsb.gc.ca/eng/stats/pipeline/2011-07/p2011-07-t1.asp September 23rd, 2011
[3] National Energy Board of Canada. September 7, 2011. http://www.neb.gc.ca/clf-nsi/rthnb/whwrndrgvrnnc/rrspnsblt-eng.html.

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