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BP Exploration (Alaska) Inc. (BPXA) - Corrosion Monitoring and Prevention Program

Overview - Oil Field Corrosion

The oil formations at Prudhoe Bay and other North Slope fields produce a mixture of oil, natural gas and water – these three components need to be separated before the oil can be delivered to the Trans Alaska Pipeline System. The presence of water and natural gas, together with physical properties of the hydrocarbon reservoir can result in substances that are corrosive to internal components of carbon steel equipment common in oil fields, such as pipelines. This corrosion generally occurs due to the presence of carbon dioxide and/or bacteria.

1. Carbonic acid corrosion can occur when associated natural gas contains carbon dioxide dissolves in the water to form carbonic acid. This is the most common type of corrosion in the Prudhoe Bay facilities.

2. Bacterial corrosion can occur when bacteria are present and conditions are conducive to the growth of bacteria. The bacteria and bacterial byproducts can also result in internal corrosion Bacterial corrosion.

Both types of internal corrosion are mitigated through the use of chemical corrosion inhibitors, biocides and maintenance pigging.

The produced liquids may also entrain sand and rock particles which, at high velocity in the pipelines, can erode the wall of the pipe. In addition, moisture on the outside of pipe from snow, rain, and condensation can cause external corrosion if they contact the pipe.

Program Objectives and the "Fit for Service" Strategy

The objective of BPXA's corrosion monitoring and prevention program is twofold –

1. Control corrosion in all equipment, pipelines, vessels and tanks.
2. Provide assurance that the equipment is in good condition – meaning it is safe to operate and will not release fluids into the environment.

Equipment that is in the safe and environmental sound condition described in objective two above is also referred to as being "Fit for Service". BPXA has designed our corrosion monitoring and prevention program around a "Fit for Service" strategy that has four key elements –

1. Identification of corrosion mechanisms for various equipment and lines (internal, external, erosion).
2. Frequent monitoring of corrosion rates through various corrosion monitoring programs.
3. Periodic inspections to identify corrosion damage and pipeline wall thickness.
4. Mitigating the progress of corrosion.

Specific Processes and Procedures

Numerous processes and procedures are utilized to deliver the Fit for Service strategy. These processes and procedures are summarized below.

Corrosion Monitoring: A variety of techniques are used to monitor corrosion rates, including the use of metal weight loss coupons at approximately 1,500 locations. These coupons are inserted into the fluid stream. After the coupons have been exposed to the stream for a set period, they are removed and analyzed to determine the coupon corrosion rate. In addition, BPXA has installed 90 electrical resistance corrosion probes that continuously monitor the corrosivity of the fluids. The data obtained from the corrosion coupons and probes are used to adjust corrosion inhibitor injection rates and to initiate other corrosion mitigation actions.

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Corrosion Mitigation: A variety of methods are used to mitigate corrosion. The type of method used is dependent upon the type of corrosion most likely to occur at a given location. CO_2 or carbonic acid corrosion is typically controlled by injection of corrosion inhibitor chemicals into the production streams. BPXA currently injects over 2.5 million gallons of corrosion inhibitor annually.

Bacterial corrosion is controlled by injection of a biocide chemical. In addition, many corrosion inhibitors contain quaternary amines, which can help control bacterial corrosion. Mechanical pigging of pipelines is also used to remove solids and water that may build up in low points in the pipelines over time. BPXA has a team dedicated to pipeline pigging activities. Maintenance pigs are run approximately 370 times per year in a variety of three phase production, produced water, and seawater pipelines.

External corrosion of pipelines is controlled by replacing wet insulation or degraded coating with dry, sealed material.

Inspection: BPXA has one of the largest inspection programs in the oil and gas industry and currently inspects over 100,000 individual locations every year, for both internal (60,000) and external (40,000) corrosion. North Slope pipelines are unique compared to most oil and gas operations, as North Slope pipelines have been built above ground to prevent thawing of the permafrost and to protect the tundra. Even in areas where the pipelines are below ground, such as at road or caribou crossings, the pipelines are cased (i.e. placed within another larger pipe). The above ground pipeline configuration is advantageous to the corrosion monitoring program as it allows for significantly easier access for inspection compared to a buried pipeline.

Below are the inspection programs used to identify specific forms of corrosion damage.

- Corrosion Rate Monitoring (CRM) programs repeat inspections at the same location, typically every 6 months, to look for loss of metal.
- Corrosion Under Insulation (CUI) programs are designed to detect external corrosion that can be hidden by the thermal insulation that is on the outside of the pipelines.
- Erosion Rate Monitoring (ERM) is conducted at locations that could be susceptible to erosion inside the pipe due to high velocities and fluid characteristics. ERM is typically performed at bends every 3 months.
- Comprehensive Inspection Program (CIP) is an annual program aimed at detecting new internal corrosion mechanisms and new locations of corrosion. It also monitors damage at known locations and thus assesses the extent of degradation and fitness-for-service.
- In-Line Inspection Program is designed to detect internal and external damage but still requires verification of actual damage by Ultrasonic and/or Radiographic Inspections.

A variety of inspection techniques are used in the inspection programs described above. The techniques include **visual, ultrasonic, radiographic, magnetic flux, guided wave** and **electromagnetic,** and each can be used to detect different types of damage. The basic technology in some of these techniques has also been built into devices which crawl, climb or travel along equipment to provide a "damage map" of large areas or all of a piece of equipment. For example, **smart pigs** can inspect the surface of an entire pipeline. Smart pigs and other automated techniques are helpful in identifying locations that should be more closely monitored using one of the point inspection methods, e.g visual, ultrasonic, radiographic. Smart pigs can also provide assurance that the spot inspections are truly representative of the pipeline condition. Again, the above-ground design of the North Slope pipelines makes it possible to monitor specific locations with potential damage with much greater frequency compared to buried pipelines.

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The risk based inspection program includes a number of factors contribute to the selection of locations, extent and frequency of inspection programs. Some of these include but are not limited to equipment condition, rate of wastage, transported fluids, personnel safety and environmental concerns.

Corrosion Program Resources and Results

BPXA has been funding an ever more aggressive Corrosion, Inspection, Chemical (CIC) program to address the challenges posed by corrosion. Twenty-five BPXA engineers and technical specialists are teamed with an alliance of world leading suppliers of specialist services for inspection and chemicals. The 2006 annual budget for the program is $71 million, an increase of 15 percent from 2005, and 80% from 2001.

Most important, a substantial improvement in control of internal corrosion in three phase flow lines (i.e. pipelines that transport oil, gas and water) has been seen over the past several years. The following graph illustrates the significant improvement in corrosion rates experienced since the early 1990s and the effective management of the corrosion rate over the past ten years. This plot shows the average corrosion rate on major production flow lines.