Operator:
TRANS ALASKA PIPELINE SYSTEM

Low Flow Impact Study

FINAL REPORT

June 15, 2011

Prepared by the Low Flow Study Project Team at the request of Alyeska Pipeline Service Company

Executive Summary

This report presents findings, mitigations, and recommendations of the Low Flow Impact Study (LoFIS) for the Trans Alaska Pipeline System (TAPS). The study was performed to evaluate the potential risks to future operation of TAPS at throughputs and oil temperatures that are considerably lower than those assumed for the original pipeline design.

Conclusions

The LoFIS identified water dropout and corrosion, ice formation, wax deposition, geotechnical concerns, and other issues that pose operational risks to the TAPS at throughputs ranging from 600,000 barrels per day (BPD) to 300,000 BPD (note that all references to throughput volumes represent volumes at Pump Station [PS01] unless otherwise indicated). However, the TAPS can continue to be operated safely and with reasonably high operational confidence down to throughputs of about 350,000 BPD if the following important issues are addressed to maintain normal flowing operation at these low throughputs:

- Water dropout and corrosion: The specified maximum water content in the TAPS is 0.35 percent, although short-lived spikes as high as several percent occasionally occur. The water, which is typically entrained in the oil in the form of small droplets for current throughputs of roughly 630,000 BPD, is expected to start separating out in a flowing layer at the bottom of pipe when the flow drops below roughly 500,000 BPD. As a result, water concentrations will increase, especially at pipeline low points and upward-facing slopes, which will increase the potential for internal corrosion damage at the bottom of pipe.

- Ice formation: Unless the crude oil is heated, its temperature will drop below the freezing point of water during the winter months as flow rates decline below roughly 550,000 BPD. Engineering analysis and testing indicate that freezing of the water in the oil is very likely at this point. Operational impacts could include icing and consequent disabling of check valves (CVs); ice accumulations at tees, bends, instruments, strainers, and inside mainline valve bodies; and formation of ice in water slugs created via pig passage.

  It is important to note that the hot residuum that is returned to the pipeline by the refineries at North Pole, Alaska is currently an important source of heat. If this heat

source is not reliable or available and an alternate source of heat is not implemented, the throughput at which wintertime crude oil temperatures consistent with freezing of the water in the oil is increased from 550,000 BPD to 780,000 BPD.

- Wax precipitation and deposition: Wax deposition on the pipe walls has increased significantly since the crude oil temperature dropped below the wax appearance temperature (roughly 75 ºF) in the mid-1990s. Wax deposition will continue at current levels as the throughput declines, even if the oil is heated in the future. In addition, settlement of wax particles in the pipeline will occur as a result of lower oil flow velocities and during pipeline shutdowns. The wax deposited on the pipe wall and the settled wax particles will then be collected and hardened by scraper pigs.

- Geotechnical concerns: Lower crude oil temperatures will permit soils surrounding the buried portions of the pipeline to freeze, which will create ice lenses in certain soil conditions. Ice lenses could cause differential movement of the pipe via frost heave mechanisms. Assuming no heating of the crude oil, ice lens formation is predicted to occur at a throughput of 350,000 BPD. Unacceptable pipe displacement limits and possible overstress conditions in the pipe would be reached at a flow volume of 300,000 BPD.

- Additional operational issues:

  - Feasibility of pigs to remove wax at throughputs less than 350,000 BPD: Pig bypass orifices must be large enough to maintain sufficient bypass flow to disperse the waxy sludge in front of the pig, while remaining small enough to provide enough differential pressure to overcome frictional resistance and keep the pig moving. Additional risk may be posed by the buildup of wax deposits in the interior spaces of the pig that further reduce the bypass flow rate. The buildup may be sensitive to the pig design.

  - Reduction in pipeline leak detection efficiency: Instrument limitations and the increased impact of additional slackline areas could degrade the leak detection capability and create a potential inability to meet regulatory leak detection requirements.

  - TAPS shutdown and restart issues: During shutdowns, the water in the pipeline flows and settles to pipeline low points. The potential for water to freeze and potentially plug the pipeline increases at lower throughputs (and commensurate lower pipeline temperatures). Even if ice blockages do not occur, the ice that forms can negatively impact downstream pump stations if the ice passes into relief valves, mainline pumps, or other sensitive equipment. Significant wax accumulations are also possible during shutdowns due to settlement of precipitated wax in the cooling crude and may cause significant problems for cleaning pigs following the shutdown. Restart problems can result from gelling of the crude oil in the pipeline at low temperatures.

Absent any mitigation of these issues, the reliable operating throughput for the pipeline is about 550,000 BPD under normal conditions.

With the mitigations in place, the reliable operating throughput is estimated to be about 350,000 BPD. Flow volumes of less than about 350,000 BPD subject TAPS operations and pipeline integrity to greater degrees of uncertainty that require investigation and study beyond that accomplished through the LoFIS. As flow rates decline below 350,000 BPD, issues related to low flow will increase the problematic impact on the TAPS operation. Measures to mitigate these issues utilizing the existing 48-inch pipe at throughputs below 350,000 BPD have not been determined at the date of this report.

Specific areas of uncertainty at throughputs below 350,000 BPD include the following:

- Increasing volumes of water accumulation at pipeline low points and in front of pipeline pigs and the associated issues of:
  - Additional corrosion caused by the water.
  - Locating where water will accumulate during a pipeline shutdown.
  - The potential for large accumulations of ice during winter shutdowns of the pipeline.
- The ability to pig the pipeline at low volumes due to throughput velocities that are insufficient to sweep away the wax in front of the pig.
- Unknown operational factors related to the increased numbers of pipeline pigs and multiple pigs in a pipeline segment.
- The potential for large accumulations of wax related to increased wax precipitation and the ability to keep the wax particles entrained within the crude oil stream at low velocities.
- The ability to monitor corrosion with instrumented pigs in the slackline areas.

- The ability to utilize instrumented pigs at low velocities with increased wax accumulations and longer transit times.
- The viability of internal corrosion chemical treatments.
- Cold restart issues related to the increased percentage of residuum in the southern pipeline segment and associated increased gel strengths.
- The effects of crude heaters on the generation of wax.
- Ability to reliably operate and manage large numbers of crude heaters to maintain the crude oil above freezing at low flow rates and to provide provisions for pipeline slowdowns.
- Questionable viability of the leak detection system at low flow rates.
- Operational unknowns caused by extremely low throughput rates that result from pipeline slowdowns when the throughput is already low.
- Operational unknowns resulting from a combination of issues such as ice and wax accumulations after a shutdown, restarting the pipeline with ice, and gelled crude oil.
- The composition of future crude oil and the resulting effects of high proportions of heavy and viscous oil in the pipeline.

Each year that volumes decline further, the TAPS is operated at a throughput never before experienced, not even when the pipeline was first started. Likely there are issues related to operating the pipeline below 350,000 BPD that have not yet been identified.

Recommendations

The Plan Forward presented in Section 3 was developed to enable safe operation of the pipeline at throughput of approximately 350,000 BPD. Reservations about current knowledge of pipeline physical processes at lower flow rates (as described above) decrease confidence that the pipeline can be reliably operated at throughputs lower than 350,000 BPD.

A summary of major recommendations is provided below:

1. Minimize the risk of ice formation in the winter. Implement strategies to maintain crude oil temperatures on the pipeline at a level that will allow reliable cold weather operations. If heat from the sources at North Pole cannot be relied upon, additional heat sources that are capable of duplicating heat from the sources at North Pole may be required. In addition, heat the oil in proximity to but upstream of locations subject to low oil temperatures, including PS03, PS04, PS05, and PS09, and possibly PS07. Consider enhancing the insulation of the aboveground portions of the pipeline north of North Pole to minimize the ice formation during extended winter shutdowns and reduce the cost of running heaters. Finally, establish a minimum temperature of 105 ºF for crude entering the TAPS from fields on the North Slope.

2. Mitigate freezing of water in the pipeline during an extended wintertime shutdown. Identify contingency measures and equipment to enable the handling of ice and wax pushed into the pump stations following shutdown, and provide bypass to the back pressure control valves at the Valdez Marine Terminal (VMT) to allow for ice to enter the terminal without plugging the control valves.

3. Develop procedures to reduce the risk of a throughput interruption that will result in pipeline crude oil temperatures below the freezing point. Maximize available VMT storage capacity during winter months, and investigate a winter wind loading restriction waiver for the VMT to reduce potential for pipeline slowdown.

4. Modify the current water specification to prohibit water slugs above 0.35 percent. Such modification will limit the amount of water contained in the crude oil stream. This will reduce the amount of water that settles out to pipeline low points during winter shutdowns and reduce the number of low points with significant water accumulations.

5. Implement contingency procedures, practices, and facilities to minimize the potential formation of ice as a result of extended pipeline shutdowns and reduced throughput in the winter months. Further evaluate the installation of enhanced insulation at critical pipeline low points to reduce the rate of ice formation during an extended pipeline shutdown. Evaluate contingency use of freeze point inhibitors. Evaluate contingency equipment to locally respond to water accumulations during a shutdown. Finally, implement real-time monitoring and off-line simulation tools to track and forecast pipeline crude oil temperatures, pipeline water accumulations during shutdowns, and associated ice formation.

6. Reduce the risk of internal pipeline corrosion from increased water holdup in the pipeline by regularly injecting corrosion inhibitor and biocide chemicals into the

crude stream at PS01 and PS04.[1] Continue regular pigging and modify pig designs, as required, to sweep out increasing amounts of accumulated water and wax in the pipeline. Finally, implement real-time monitoring and off-line simulation tools to track and forecast pipeline water transport on a transient basis. At throughputs below 400,000 BPD, reduce the water specification to 0.2 percent to reduce the accumulation of water in flowing conditions.

7. Manage continued or increased wax deposition by implementing a pig washer to reduce the costs of pig cleaning and wax disposal as a hazardous waste; installing a pig launcher and receiver at PS09 or other locations having the capacity to handle ice and wax before mainline units are affected; and evaluating the adequacy of the VMT tank mixers to handle the increased solids. Establish a program to monitor wax and crude oil solids to include regularly monitoring changes in crude oil composition and impacts to gelled crude rheological models. In addition, enhance the Alyeska DRA Monitoring and Analysis (DRAMA) software to enable better monitoring of wax accumulation due to increased pressure drops between pig runs.

8. Implement a formal pigging technology development program that evaluates water and wax issues, establishes an optimal pigging frequency, conducts an annual review of the pigging program and pig design, continues to evaluate the viability of pigging and pig design with respect to higher precipitated wax volumes at low velocities, and determines the viability of pipeline pigging following a pipeline shutdown, including removal of wax and ice from the pipe.

9. Revisit Alyeska's previous pipeline cold restart analysis and implement a continuing cold-restart evaluation program. Include periodic evaluation of the crude oil gel strength and other rheological model parameters; assessment of the impact of North Pole residuum on crude properties and restart; development of new analytical procedures for use with Alyeska's cold restart model; and assessment of the impact of ice at pipeline low points, crude oil heating, and possible presence of pipeline pigs. In addition, perform a cold restart analysis every 5 years.

10. Utilize the current curvature pig-monitoring program to monitor pipeline frost heave to ensure that reduced oil temperatures do not create an overstress condition in the buried pipe.

[1] Note that residual monitoring and neutralization of corrosion inhibitor and biocide chemicals would be required in Valdez before draining treated water into the BWT system.

11. Perform a detailed analysis of field instrument capabilities at low flows and of effects to the leak detection system from degraded field data and lower flow rates.

12. Conduct a probability analysis to determine a winter design shutdown duration and associated credible minimum ambient temperatures. Conduct a probability analysis to also determine design pipeline slowdown criteria. These criteria will be utilized as part of the design basis for low flow mitigation measures.

13. Supplement the Department of Revenue forecast for timing of low-flow related mitigation projects with the forecasting algorithm developed by the LoFIS team based on past throughput decline rates. Update the algorithm yearly.