

CENTRIFUGAL PUMPS IN HEATED BITUMEN PIPELINE SERVICE

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ABSTRACT

World scale deposits of oil sands (bitumen) in Northern Alberta are being developed to extract hydrocarbons from the sand. A pilot facility was built to pump raw heavy tar-like bitumen in a heated state through an insulated and buried long distance pipeline in order to determine technological and economic viability. This paper describes the special considerations in the selection, design, installation, and control of pipeline pumps to transport high viscosity heated bitumen.

Loss of heat in the pumps and the pipeline would increase viscosity of the bitumen, which could not be recovered and would result in a permanent failure of the facility. To increase pump

reliability, standard mechanical seals, auxiliary piping, and bearings were modified. Also affecting the pump design was the need to manufacture the pump station in modules in Edmonton, Alberta, then transport the modules 500 km (315 miles) to the site for assembly. This was due to the remote, cold, arctic-like, and high labor cost environment of the site. For flow rate and pressure control, the pumps were powered by a variable speed electric motor drive. Redundant safety systems were used to ensure the pumps and pump station were operational and 100 percent available.

INTRODUCTION

Enbridge accepted a challenge from a large integrated oil producer to build a long distance, 35 km (22 mile) buried and insulated pipeline for heated bitumen in Northern Alberta. The bitumen had to be kept above 90°C (194°F) to remain pumpable. If the pipeline were shut down for more than two days, restarting the pipeline was unlikely.

This paper discusses primarily the design and operation of the main pipeline pumps at the initiating pump station at MacKay River in Northern Alberta, (refer to Figure 1 for a map of the location). The pumps were required to transport hot bitumen, with a high degree of reliability due to the consequences of losing the facility if the bitumen cooled too much. Particular attention was given to the mechanical seals and seal leak detection system, typically the weakest link of the pump. The standard auxiliary piping connections were modified due to the need for heat tracing and insulation. Modular construction of the pump station dictated steel foundations and supports.



Figure 1. MacKay River Pipeline Map.

The paper also discusses the pump and station controls and protection systems used to increase the reliability of the pump station, particularly since the station was unattended and remotely operated. Winter conditions could reach -40°C (-40°F), and, in the summer, the muskeg made some areas of the pipeline practically inaccessible to vehicles. As a pilot project, many system redundancies were incorporated to determine if the concept was feasible on a larger scale. While there are other heated oil pipelines, this pipeline explored new territory in terms of length, operating temperatures, and fluid characteristics.

PUMP SUMMARY

The three main pipeline or shipping pumps are a multistage, horizontally split, between-bearings three stage pump; API 610 type BB3. The pumps have 150 mm (6 inch) suction and discharge nozzles and approximately 250 mm (10 inch) impellers, driven by a 600 hp, 3600 rpm motor mounted on a common steel skid baseplate. Each pump can be driven by a variable frequency drive for flow control and soft start; however, the single 600 hp variable frequency drive (VFD) can only run one motor at a time.

There are other smaller booster pumps at the pump station. Two 150 hp end suction API pumps boost the pressure from the bitumen storage tank to the mainline pumps. A single 100 hp vertical inline pump pressures the diluent piping supply system. Two 40 hp vertical inline pumps circulate the heated glycol for the heat exchangers and the heat tracing system. Other small process pumps are required on a densitometer loop, sump tanks, and a vapor recover system.

BACKGROUND

With inclusion of the vast oil sands deposits in Northern Alberta into statistics compiled by the US Energy Information Administration, Canada recently jumped from more than 20th place to the second country in the world in terms of proven oil reserves (PetroleumWorld, 2003). The oil sands are not a new discovery; natives used the gooey tar-like oil deposits (called bitumen) to seal birch bark canoes for hundreds of years, and bitumen was first seen by Europeans 225 years ago (Syn crude, 2003). However, commercially viable extraction methods began only 25 to 35 years ago on the shallower surface deposits. Gigantic shovels, trucks, drag lines, and conveyors move the mined sand to separation facilities to refine the bitumen into a synthetic crude for pipelining to distant markets. The change in Canada's reserve figures has primarily resulted from a new technique to extract the oil from deeper deposits not recoverable by surface mining techniques.

Steam-assisted gravity drainage, or SAGD ("SagD"), as it is commonly referred to in the industry, allows the recovery of bitumen from the buried oil sands deposits. Numerous steam injection wells drilled into the formation heat the bitumen to reduce its viscosity and to separate it from the sand particles. The bitumen flows by gravity into separate horizontal recovery pipes located under the oil sands and is pumped to the surface. Directional drilling technology enables the precise placement of drill pipe in a horizontal position far from the drilling rig. Small slots in the recovery pipe allow the bitumen to flow into the pipe but keep the sand out. Due to the underground steam heating, the hot bitumen flows and is pumped to the surface for further processing (Figure 2).

Bitumen has the characteristics of roofing tar. With a viscosity of two million centipoise at 10°C (50°F), pumping the bitumen at ambient temperatures is practically impossible. The oil sands industry has developed several techniques to overcome this problem. The oldest upgraded plants essentially cooked the mined bitumen and sand in giant vessels with water to separate them; then cracked, hydrotreated, and decoked the bitumen to produce a light high quality synthetic crude. However, locating the upgrading process closer to markets and existing refineries would require pumping the bitumen hundreds of miles from where it is extracted.

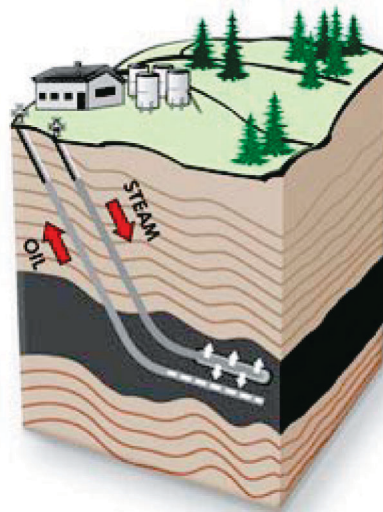


Figure 2. SAGD Bitumen Recovery Technique. (Courtesy of Petro-Canada)

This is normally accomplished by mixing the bitumen with a light hydrocarbon, or diluent, to reduce its viscosity, typically a natural gas condensate or light crude. However, light hydrocarbons suitable for dilution are costly, and natural gas condensate, for example, is not readily available in large quantities. Therefore, petroleum companies recycle the diluent by extracting it at the refinery, and then ship it by pipeline back to the oil sands plants. The costs of separating the diluent, building a separate diluent return pipeline, and operating a separate pipeline reduce the economics of oil sands extraction.

There are many cost benefits to pumping the bitumen without diluent. One method to accomplish this is heating the bitumen to reduce its viscosity to pumpable levels. This requires maintaining the bitumen at temperatures of 90°C to 130°C (194°F to 266°F) in an insulated pipeline. Since a long heated hydrocarbon pipeline has not been attempted anywhere in the world for these temperatures and distances, particularly in this climate, there were several challenges and technology hurdles.

The authors' company was chosen to build a heated bitumen pipeline for a large petroleum producer from their new SAGD facility at MacKay River to their Athabasca pipeline where the bitumen would be blended for shipping to North American markets. With assistance from a local consulting firm, the initiating pump station and pipeline were designed and built in 2001. The many new technologies used on the project, combined with good engineering, ensure the station and pipeline are operating very well.

WHY CENTRIFUGAL PUMPS

The criteria for selecting the main shipping pumps for the heated-bitumen pipeline included the requirement to overcome frictional and static losses in the pipeline system and the capability to pump diluted bitumen at reduced flowrates. Three alternatives were considered:

- Three screw positive displacement pumps
- Twin screw positive displacement pumps
- Multistage horizontal centrifugal pumps

Centrifugal pumps were selected for the following reasons:

- Centrifugal pumps are technically feasible considering the bitumen operational parameters.
- Three pumps connected in series meet the design flowrate and the discharge pressure required after a period of extended shutdown (i.e., two days).

- Only one pump is required for normal operation.
- Pump efficiency is 62 percent, which was within acceptable limits.
- Product can be blended on the suction side of the units during upset conditions.
- Centrifugal pumps can also handle low viscosity products such as diluent or diluted bitumen.
- Centrifugal multistage pumps are more cost effective than screw pumps.

Three screw pump option was not selected for the following reasons:

- Due to pump capacity limitations, three units installed in parallel configuration are required to meet the design flowrate and the discharge pressure after a period of extended shutdown (two days).
- Screw pumps are highly susceptible to products with low viscosities and to particulate.
- Blending is not allowed on the suction side to preserve the pump rotating elements when pumping low viscosity diluent.
- Screw pumps require installing an additional high-pressure plunger type pump for injecting diluent or diluted bitumen.
- Cost of the three screw pumps is 100 percent higher than the centrifugal multistage pumps.

Two screw pump option was not selected for the following reasons:

- Due to pump capacity limitations, three units installed in parallel configuration are required to meet the design flowrate and the discharge pressure after a period of extended shutdown (two days).
- Although two screw pumps are not as susceptible to water or particulates in the product stream, efficiency is lower than the three screw pumps, requiring bigger drivers.
- Pricing of the two screw pump is 50 percent higher than the centrifugal multistage pumps.

FLUID PROPERTIES

This bitumen transportation system uses heat rather than dilution to keep the flowing viscosity of the bitumen within acceptable limits. The pump station is designed to deliver bitumen to the pipeline at temperatures up to 120°C (248°F). The maximum allowable flowing temperature is limited by the pipeline coating design and stresses that could be induced by differences in pipe installation and operating temperatures. The bitumen is received from the production facilities at temperatures between 90°C to 95°C (194°F to 203°F) and heated to 120°C (248°F) using glycol in a set of two shell and tube heat exchangers (Figure 3).

The pipeline must always be operated at a sufficiently high temperature so that in the event of an unplanned shutdown, the system can cool for a specific period of time while allowing restart using existing pumping equipment. This shutdown window, also called critical period of time, is highly dependant on factors such as flowrate, pipeline insulation thickness and conductivity, ground temperature profile along the pipeline route, and length of the pipeline. In this design, a critical period of two days was established based on operability reviews. To achieve the two-day pipeline shutdown window, a minimum flow rate of 112 m³/hr at 120°C (493 usgpm at 248°F) of raw bitumen must be maintained before the pipeline is shutdown. Figure 4 shows the pipe temperature drop after a shutdown. Three pumps in series are required after the two-day shutdown period to generate sufficient pressure to overcome the high frictional losses due to the decrease in bitumen temperature and increase in viscosity.

The viscosity of the bitumen is highly affected by temperature. Table 1 shows the viscosity/temperature relationship for raw bitumen.

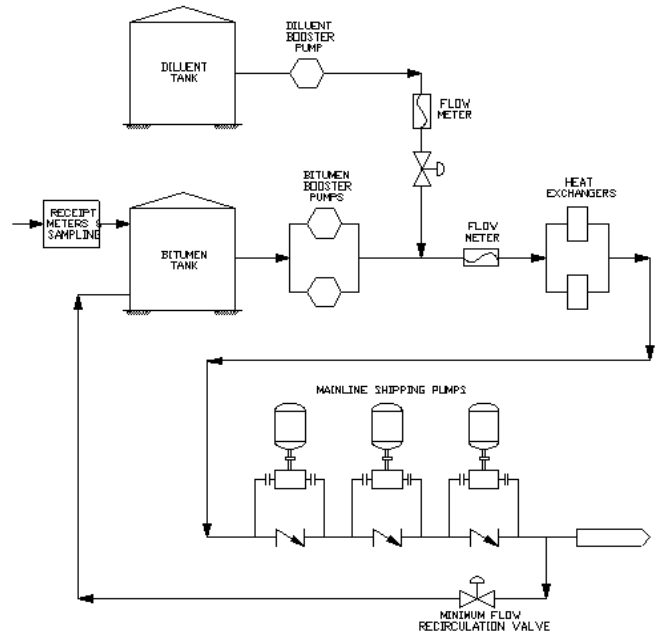


Figure 3. MacKay Pump Station Schematic.

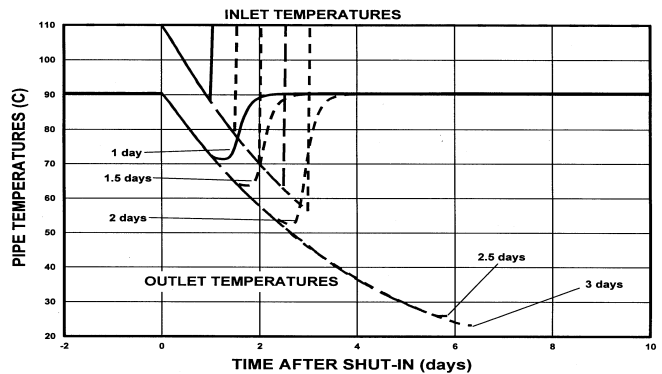


Figure 4. Viscosity/Temperature Relation for Bitumen Blends.

Table 1. Viscosity/Temperature for Raw Bitumen.

Temperature Degree Celsius	Bitumen Viscosity – Cp Base Case	Bitumen Viscosity – Cp Worst Case
130	51	70
120	75	105
110	116	165
100	188	275
90	327	490
80	613	944
60	2865	4688
40	22,118	38,403
20	349,262	649,598
10	1,998,627	3,850,100

Bitumen density range: 1013 to 1015 kg/m³ at 15°C (60°F)
 Sediments and water (S&W): Less than 0.5 percent

Figure 5 shows a viscosity/temperature comparison between bitumen, diluent, and some blending products as well as the allowable operating envelope of between 100 cst and 327 cst.

Diluent is used for blending operations. After diluent injections of 40 percent or higher on a volumetric basis, the composition of the bitumen is changed to the point that the viscosity is not an

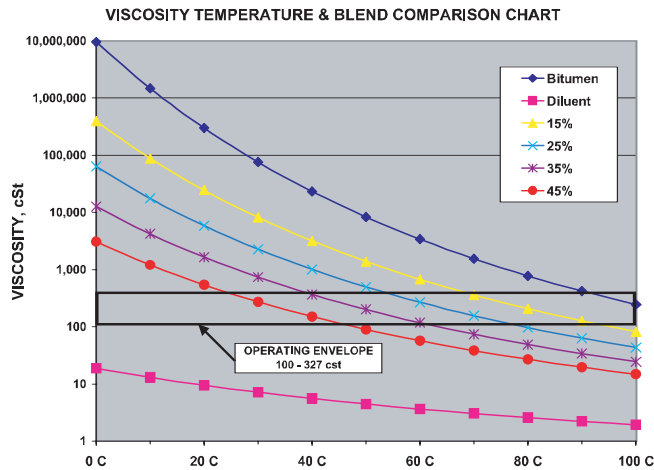


Figure 5. Relationship Between Pipe Temperatures and Time after Shutdown for 90°C to 110°C (194°F to 230°F) Inlet Pipeline Temperatures.

issue, and the pipeline can be restarted independently of the product temperature. The diluent properties are as follow:

- Density: 860 kg/m³ at 15°C (60°F)
- Viscosity: 12 cst at 10°C (50°F)

MECHANICAL SEAL DESIGN

The mechanical seal is the most sensitive and critical component in a pump. If not properly designed and installed, extremely tight running clearances, high temperatures, brittle materials, and many small machined components in a complicated package often result in early failure of a mechanical seal. As such, a major effort went into the mechanical seals to ensure the pumps are reliable. The seals must function with both high viscosity bitumen and low viscosity diluent, hot and cold temperatures, clean and dirty product, and high and low suction pressures. Since one or two pumps may be idle for extended periods of time with bitumen in the mechanical seal, the seal faces must be kept hot to prevent the bitumen from hardening.

The type of mechanical seal selected was based on the manufacturer's recommendation from successful applications in high viscosity Venezuelan crudes in South America. The seal is a cartridge-mounted single seal with carbon throttle bushing cartridge designed for high pressures and particulate (Figure 6). The seal is provided with a Plan 11 seal flush taken from the first stage impeller discharge. The company's success with conventional heavy crudes dictated the use of hard seal faces. Reaction-bonded silicon carbide was used for both the stationary and rotating faces to provide wear resistance against entrained sand, lubricity in low viscosity fluids, and dimensional stability in suction pressures ranging from 455 kPa to 6660 kPa (66 psig to 966 psig). A single large enclosed pusher spring provided protection against hang-up from packed solids. The spring pushes against an elastomeric U-cup, which acts as the primary dynamic seal under the rotating seal face. The U-cup is both spring and pressure energized to provide high and low pressure sealing capability.

Due to the high viscosity of the bitumen at ambient temperatures, the seal faces must be maintained around 100°C (212°F). This is accomplished by jacketing the gland face and flowing hot glycol from the plant heat tracing system through the jacket. Tangential inlet and outlet ports in the gland plate ensure a circulation flow around the heating chamber to evenly heat the gland plate. An insulation blanket and heat tracing on the exterior of the stuffing box also keep the bitumen in the stuffing box hot.

Special feature modifications include the porting of the seal flush through the top of the stuffing box rather than the gland plate.

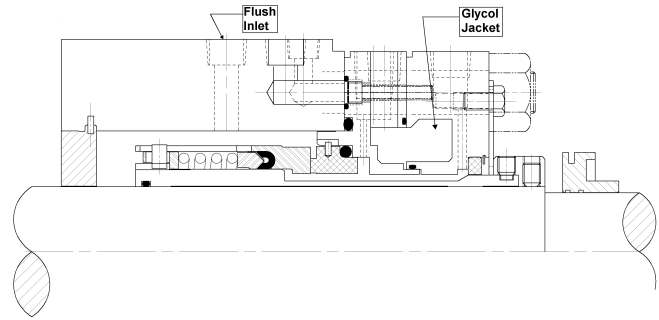


Figure 6. Mechanical Seal.

This allows the seal to be removed without disturbing the seal flush piping.

The seals have operated for over 2000 hours without any leakage problems.

SEAL LEAK DETECTION

Leakage past the primary seal face is piped directly from the drain port of the gland face through a hole cut in the bearing bracket to a sump system. The hole is located and sized to allow a short 12 mm (1/2 inch NPT) pipe nipple to be inserted into the hole and screwed into the gland plate. The seal leakage piping is heat traced to prevent any bitumen leakage from congealing and blocking the drain line. Seal failure detection is provided by a pressure switch monitoring the pressure in the annulus between primary seal and a solid carbon throttle bushing. Minor seal leakage will flow through the 4 mm (.157 inch) drain drilling in the gland plate from this annulus to the sump tank. Larger flow rates will create a pressure rise due to the restriction in the gland plate and trip the pressure switch at 35 kPa (5 psi), which initiates a pump shutdown. The pressure switch is threaded into the stuffing box bore and measures the seal pressure via a cross drilling from the gland plate to the stuffing box bore. This allows the seal to be removed without affecting the pressure switch installation.

Due to concern that a major seal leak or a seal drain blockage would force bitumen to flow past the throttle bushing and leak out of the bearing bracket drain, the bearing bracket is also connected to the sump system. However, blockage of the mechanical seal drain system has not occurred, and there has been no leakage past the throttle bushing. This indicates that the primary seal is holding and the drain system is effectively handling any minor leakage.

HEAT TRACING AND INSULATION

The pump station uses a glycol heating system to increase the temperature of the bitumen before shipping and to heat trace all bitumen and drain piping. The glycol selected is a mix of 60 percent triethylene glycol and 40 percent water. The glycol is operated in a closed circuit, heated in a natural gas fired water tube boiler, and circulated with two single-stage vertical centrifugal pumps.

The heat tracing system is designed to keep the bitumen piping and equipment at a minimum temperature of 90°C (194°F) with supply and return headers and manifolds when the product is not flowing. To increase the effective heat transfer rate, all tracers are bonded to the pipe with heat transfer cement. Additionally, all piping is insulated using urethane foam and jacketed with aluminum sheets secured with screws and stainless steel bands (Figure 7).

For equipment, including the main shipping pumps, reusable sewn blanket insulation is used. The blanket material is Teflon®-coated fiberglass.

Due to the difficult pump casing geometry, the main shipping pumps cannot be traced with a glycol circuit. As such, electrical heat tracing is provided using a mineral insulated, two conductor heat tracing, 600 V rating, thermostatically controlled at 110°C (230°F). This heat tracing system is installed in a hairpin configuration.



Figure 7. Heat Tracing and Blanket Insulation.

AUXILIARY PIPING

All auxiliary piping is kept as simple and short as possible to minimize piping that requires insulation and heat tracing. The balance line runs tight to the pump body and is kept hot by running the pump insulation over the balance line. The Plan 11 seal flush source is taken from the first stage volute instead of the upper crossover to position it closer to the pump case. Unfortunately, the seal flush could not run close enough to the pump body to cover it with the pump case insulation, so it was separately heat traced and insulated. The main seal flush source connection to the pump case is welded Schedule 160 pipe to a point where the flow splits to both seals (Figure 8). After the tee, the flush flow continues in 19 mm (3/4 inch) stainless steel tubing, which has greater flexibility than pipe and is more resistant to vibration. The flush to the welded pipe joints and the tubing provide the best combination of rigidity and flexibility.

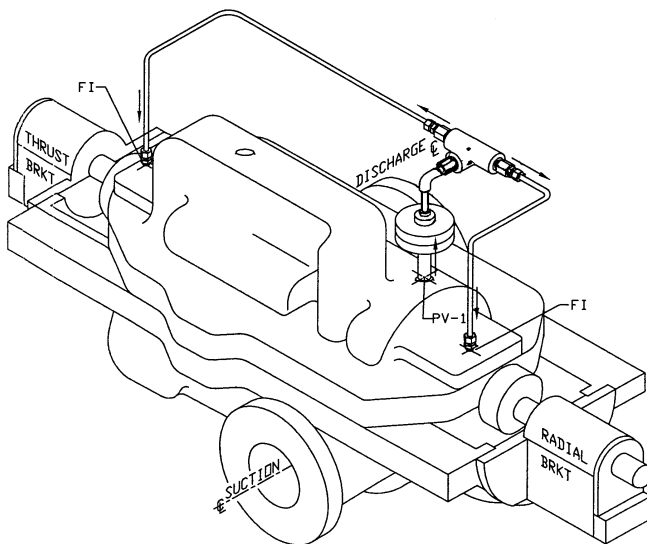


Figure 8. Pump Seal Flush Piping.

The two other piping components are the vent piping and drain piping. These are made with 25 mm (1 inch) Schedule 160 pipe nipples and socket-welded Schedule 900 ANSI flanges (Figure 9). The drain and vent lines are isolated with a locking lever ball valve. The ball valve is a single reduced port, which is smaller, lighter weight, and provides easier isolation than a gate valve. This piping is also insulated and heat traced to prevent the bitumen from congealing. One pump case drain and one pump vent auxiliary

connection were deleted from the pump at the design stage to reduce the number of external pipe connections that require insulation and tracing. These are taken off the first stage volute, which traps a much smaller volume than the upper and lower crossover passages.

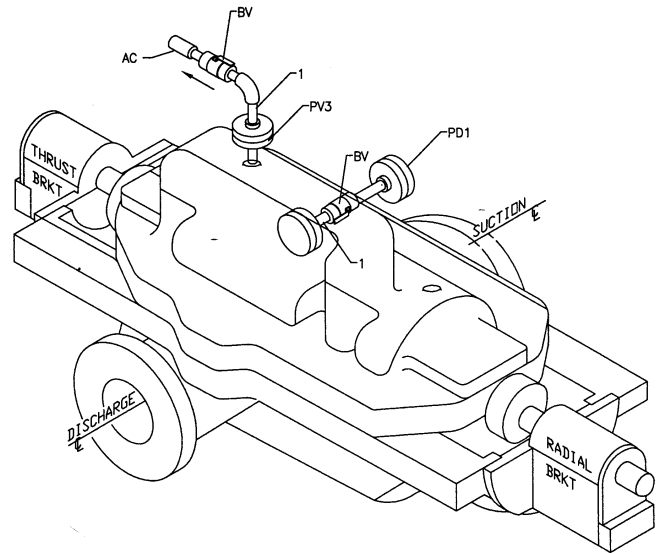


Figure 9. Pump Vent and Drain Piping.

MODULAR DESIGN

Several factors were considered in the decision to build the pump station in modules. A high cost of labor and shortage of skilled labor existed in the Fort McMurray area due to several large projects underway at the same time. In addition, the site was remote from the city and the main highway. Soil conditions required pile supports. Temperatures at the construction site could drop to -40°C (-40°F) in the winter, and wet summer conditions made access difficult. Capable manufacturing facilities with an available skilled workforce were available in Edmonton, Alberta, a city of 800,000 approximately six hours away.

BASEPLATE DESIGN AND INSTALLATION

The pump baseplate is designed as a nongrout type structural steel skid for mounting both the pump and motor in a common frame. The top of the baseplate is covered with a 6 mm (1/4 inch) steel plate continuously welded to the frame.

The pump is supplied with 3 mm (0.125 inch) solid stainless steel shims for the pump pedestals, which are welded to the structural members of the baseplate. Additionally, the pump skirts are supplied with mounting pads and benchmark lines scribed for center. These lines are punched axially for centering the pump, and transversely for alignment of the suction and discharge nozzles. For skid draining, a 50 mm (2 inch) angle-iron drip trough is provided around the skid and sloped to a 50 mm (2 inch) coupling drain point at the pump outboard end.

The completed pump baseplates are leveled and bolted to the building floor by anchor bolts welded directly to the beam flange of the main shipping pump shelter. Approximate weight of the main shipping pump building is 75 tonnes (83 tons).

PIPING DESIGN

During the station design, the nozzle loads on the pumps had to be minimized due to weight and thermal expansion of the attached piping. Because the project schedule necessitated building through the winter, it was possible for the pump suction and discharge piping to be cold during assembly and then heat up during normal operation. The installation temperature selected was -10°C (14°F)

and the operating temperature was as high as 130°C (266°F), for a total temperature swing of 140°C (280°F). The forces and moments on the pump nozzles are below two times the API 610 Table 2 limits through the use of expansion loops and spring supports. The piping adjacent to the pump is supported from the floor by an adjustable stand on a sliding base. The sliding base does not restrict horizontal movement. The U-shaped expansion loop has a vertical orientation and the piping exits the building to an elevated pipe rack (Figure 10). To keep the weight of the piping off the pump nozzles, the expansion loops are supported by commercial spring supports. The springs were preloaded in the cold condition so that when the piping expanded in length in the hot condition, the weight of the piping was balanced by the springs.



Figure 10. Station Piping Design.

DRIVE SYSTEMS

Although the pump station site is isolated, electrical power is available due to the large infrastructure of oil or tar sands extraction facilities in the region. An electric induction motor drives the pump. A “squirrel cage” motor is relatively simple, robust, contains no brushes or special windings, and is more cost effective than other motors or engine-based drivers.

The motor is oversized for the power demands of normal operation. As a component of the plant reliability system, the motors must be capable of driving the pumps under plant upset conditions, namely the minimum temperature from which the pipeline could still recover. From hydraulic calculations, each pump must be capable of generating 316 meters of head (1038 feet) at a flow rate of 265 m³/hr (1166 usgpm) with 327 cP bitumen.

A variable speed drive controller is required for pipeline flow rate and for pressure control. The VFD is capable of starting any one of the three motors but can only run one pump at a time. Once a motor is brought up to synchronous speed, it can be switched over to the power grid. The VFD must operate anywhere from 40 percent to 110 percent of 3600 rpm for greater variability in discharge pressures. This resulted in selecting a VFD capable 600 hp motor with a 1.15 service factor capable of running at 3960 rpm with 116 cP bitumen. In addition to the soft start capability, the VFD is also used to provide discharge pressure control. This eliminates the need to throttle with a pressure control valve.

The cold start torque was also verified. If the bitumen temperature drops to 60°C (140°F), the motor must produce enough torque to overcome the high loads created by the 2865 cP chilled bitumen. Speed torque curves of the driver and driven equipment were compared, and it was determined that the torque margin is sufficient.

The pump and motor are coupled with a standard flexible disk spacer coupling.

LATERAL AND TORSIONAL ANALYSIS

The authors’ company’s experience with other multistage pumps driven by variable frequency drives indicated that damaging torsional vibrations were possible (Dickau and Perera, 2000). Therefore, a torsional analysis was requested from the pump vendor. The pump vendor performed preliminary analysis, and an external consultant analyzed a damped rotor response.

The pump/coupling/motor rotor system is modeled as a mass-elastic system with one mass polar moment of inertia for each impeller, sleeve, coupling hub, and motor. The rotor system was checked to determine whether the torsional natural frequencies are less than 10 percent (API 610 clause 2.8.2.3) from any potential excitation frequencies of 1×, 2×, and 6×. Two natural frequencies were found at 5534 and 35,953 cycles per minute (CPM), and these were plotted against the excitation frequencies over the operating speed range to generate a Campbell diagram (Figure 11). One intersection point occurred with the 2× excitation and the first natural mode within the operating speed range of 1440 to 3960 rpm at a rotating speed of 2767 rpm. Therefore, a damped response analysis was required to determine whether the resonance could result in fatigue failure. Since any one of the pumps could be operated on the VFD, it is possible for the unit to run at the resonance speed for an extended period of time.

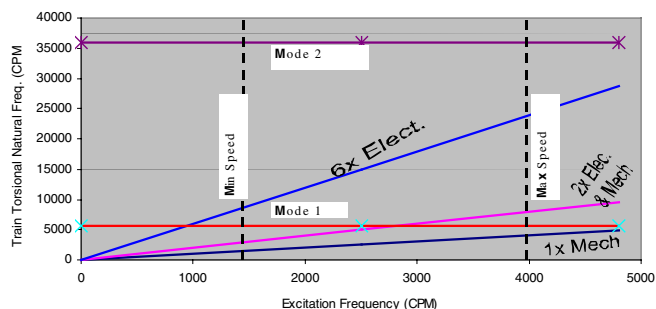


Figure 11. Campbell (Interference) Diagram.

An excitation force of 0.5 percent of the transmitted torque representing any mechanical excitation was applied at the point of highest amplitude, namely the balance sleeve (Figure 12). Although the VFD also creates a 2× excitation in the motor core, the VFD vendor stated the maximum amplitude was only 0.5 percent of the transmitted torque, and since the force was located within the motor core, which had a small amplitude, the mechanical excitations forces were considered instead. A computer calculation determined that the maximum cyclic shear stress in the motor shaft is approximately 3860 kPa (560 psi) and 2415 kPa (350 psi) in the pump shaft. Since the tensile strength of the shaft is 180 times higher than the cyclic stress, it was concluded that the pump can run indefinitely at the resonance condition without any detrimental effects.

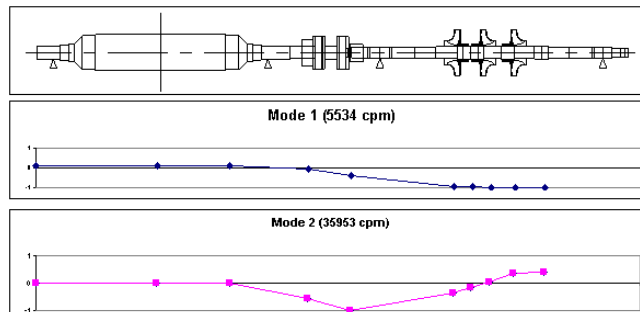


Figure 12. Mode Shape Diagram.

PUMP PROTECTION SYSTEMS

The protection equipment installed on the MacKay River mainline shipping pumps is typical for the company's pipeline systems with minor exceptions. The pumps and motors are monitored for excessive vibration, with an integrated 4-20 mA vibration transducer/transmitter located horizontally on the pump outboard bearing housing and another vibration transmitter on the motor inboard bearing housing. The vibration signals are sent to the programmable logic controller (PLC), which continually monitors the incoming signals, and alarms the pipeline operator at a vibration level of 10 mm/s (0.4 in/sec) and automatically locks out the unit at 15 mm/s (0.6 in/sec). Blocked discharge or suction valve protection is provided by a case temperature resistance temperature detector (RTD) in the third stage volute by which the PLC will lock out the pump if the temperature of the bitumen in the pump exceeds 150°C (300°F). Similarly, the outboard and inboard sleeve bearings of the pump and motor are continuously monitored by an RTD inserted into the bearing shell. While the ring oil lubrication system provides a supply of oil to the bearing and some cooling, excessive temperatures will drop the oil viscosity too low and result in wiping the bearing babbitt. The high bearing temperature alarm is established at 80°C (176°F) and the unit lockout is set at 90°C (194°F). The last component of the pump protection system is the seal leak detection system. Details of this system are covered earlier in the mechanical seal design section. Typical company pipeline seal leak detection systems on other crude pipelines use a level detector in a pipe chamber with a restriction orifice in its drain outlet. Excessive leakage accumulates in the chamber and the level detector signals a seal failure. This was not considered advisable with the viscous bitumen.

In addition to individual pumping unit protection, station protection systems ensure the pumps and pump station run reliably since an unplanned extended station outage could be disastrous. The mainline pumping units are protected against running below minimum flow by a recirculation control valve on the discharge of the pump station. A flow meter controls the recirculation flow back to the bitumen storage tank through a pneumatic control valve to maintain a minimum of 137 m³/hr (603 usgpm) through the shipping pumps. The pumps are also protected against cavitation, flashing, or other damage from low suction pressure by monitoring the station suction pressure. Two pressure transmitters for additional reliability upstream of the pumps send a signal to the PLC to prevent the suction pressure from dropping below 350 kPa (50 psi). The PLC ramps the speed of the operating pump down until the minimum suction pressure is regained. Lastly, a gas and fire detection system in the pump building will cause an emergency shutdown (ESD) of the entire station to reduce the risk of a fire from a gas leak or further damage from a fire by stopping all pumps in sequence.

REDUNDANT SYSTEMS

As stated earlier, this project is both a new design for this company and the first time such heavy hydrocarbon has been shipped so far. Many redundant controls and systems are therefore designed to reduce the risk of the pipeline stopping and the bitumen hardening to the point where restarting is impossible. These involve both mechanical and electrical equipment and controls to cover possibilities of loss of electrical power, loss of bitumen supply, a pipeline break, a failure at the delivery end of the pipeline, failure of a pump or motor, or some other equipment failure. There are also operational considerations such as availability of repair crews, repair equipment, access in the winter and summer; however, these are outside the scope of this paper. A full risk-matrix was developed that included maintenance and repair strategies, rapid response equipment, and system response decision-tree charts to ensure a pipeline repair inside of the two-day shutdown window.

The primary method to ensure that the pipeline could recover from a shutdown longer than two days is to displace the raw bitumen linefill by pumping a diluent blend down the line. A 40 percent diluent blend allows the pipeline to remain out of service for an extended period of time. If the SAGD extraction plant shuts down and there is a loss of bitumen supply to the pump station, a sufficient supply of bitumen is always in reserve in the bitumen tank to blend with the diluent and completely displace the linefill.

In the event of a power outage, the pumps could not run without other sources of power. Since power is supplied from the extraction facility, an extended power outage would have serious consequences for the pipeline and the SAGD facility. However, the pump station has backup systems to keep the station heated to prevent the bitumen from congealing. A 150 kW diesel generator onsite powers the 480 V system and keeps the glycol heating and circulation system operational. Additionally, an uninterrupted power supply (UPS) system provides station control and monitoring. The backup systems are all remotely controlled.

With the minimum flow control valve, it is also possible to circulate 100 percent of the bitumen in the pump station through the booster pumps, heat exchangers, and mainline pumps and back into the bitumen storage tank. This allows the bitumen in most of the station to be kept hot by the heat exchanger. If a single area or piece of equipment is not operational or down for maintenance, numerous connections throughout the station to the diluent piping systems allow the pipe or equipment to be purged with diluent. This prevents the bitumen from hardening and facilitates repair of the equipment.

Equipment was selected generally on a full operational unit and a 100 percent hot standby spare. The bitumen booster pumps and glycol circulation pumps are all spared 100 percent in the event that one fails. The control center can start either pump and will cycle the use of the pumps once a week to ensure each pump is operational. The three main pipeline pumps are spared such that only one pump is required for normal operation; the other two pumps are 100 percent spares. Only in the case of recovery from a two-day shutdown are all three pumps used to generate the maximum allowable station discharge pressure of 9900 kPa (1436 psi) to push the cooled bitumen.

While these backup systems may seem excessive, without previous experience in a heated bitumen pipeline, the redundant systems are justified in view of the serious consequences of a pumping system failure.

CONTROLS

The pump station is controlled by a main PLC. The pipeline can be controlled by either flow or by pressure. Under steady-state conditions, one shipping pump is normally used to deliver dry unblended bitumen on a continuous basis to the Athabasca terminal. Depending on the duration of a pipeline system shutdown, all three shipping pumps may be required for restart operations. All three pumps are required for restart after a two-day shutdown. The Mackay River station can restart unblended operations after a two-day shutdown at an initial rate of approximately 100 m³/hr (440 usgpm), and take up to one day to recover to steady-state conditions.

The pumps are configured for series operation. The system is designed for the pump operator to start mainline pumps sequentially, providing the system with the required pressure and flow increase to overcome pipeline frictional and static losses. Only one pump in the three pump train is VFD controlled at any time to provide the shipping pressure or flowrate requested by the operator.

If the required shipping rate is higher than what is possible with one pump (e.g., due to cold product in the pipeline), the operator will start another pump by opening the suction and discharge valves of the unit selected, then issuing a start command. The station PLC locks the first pump into synchronous speed, then

starts the second unit at 40 percent of synchronous speed. The speed of the second pump is then slowly increased until one of the conditions above is met. If the third unit is required to meet the desired flow conditions, it can be started the same as the second unit as described above (refer to Figure 13 for the range of pressures available over the pipeline operating range).

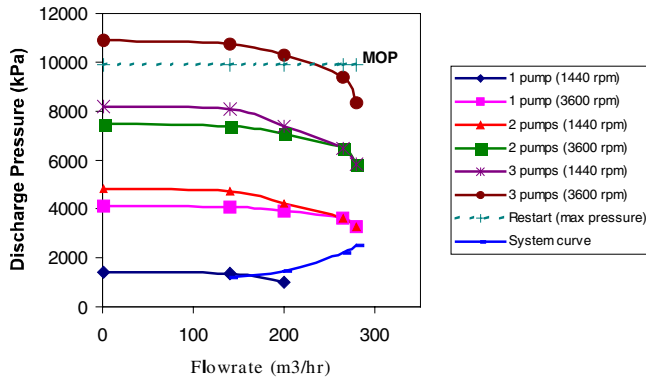


Figure 13. Performance Curves for Single, Two, and Three Pumps Operation at Various VFD Speed Control Ranges.

BEARING COOLING

Standard company practice to cool the pump bearings on other pipelines is with the pumped product, which is near ground temperatures the entire year. However, since the pumped product is hotter than the maximum allowable bearing temperatures in this application, product cooling was not possible. Several options were briefly considered. An external lube oil system was rejected due to the cost and additional mechanical and electrical equipment. A shaft mounted bearing cooling fan was rejected due to the expected high ambient temperatures inside the pump building, particularly in the summer. The pump manufacturer calculated that convection cooling of the bearing housing would be sufficient. However, the heat soak calculations from the heated pump case and shaft could not be reliably calculated and the potential temperatures inside the pump building were unknown at the time of design. Therefore, the company installed a bearing cooler or exchanger insert in the bearing housing and pumped air-cooled glycol through the exchanger from a small skid-based circulation unit outside the pump building. Operating tests showed that the maximum bearing temperature protection points would be exceeded without the external cooler.

STARTUP AND COMMISSIONING

Commissioning of the facility started with electrical tests of the main power conductors and transformers. The Mackay main voltage supply is 5 kV from the adjacent production facilities, with two transformers dropping the voltage to 480 V and 220/110 V. After completing the electrical commissioning, including the motor control center (MCC), the pump motors were energized and rotated to verify current loads without coupling to the pumps. After a laser pump alignment, the main shipping pump 600 hp motors were rotated using the VFD, initially at minimum speed of 40 percent. Main shipping motor speed was gradually increased to 100 percent of VFD speed. After the motor rotation, the pump couplings were installed and the piping systems filled.

Main shipping pump bearing temperatures were monitored carefully during the pipeline startup phase. The auxiliary bearing cooling systems using circulating glycol were necessary to keep the bearing temperatures below the alarm set point of 90 C (194 F). Due to the extremely low ambient temperatures during startup, the

radiator fans used to cool down the cooling glycol were bypassed. These fans were put back in operation at the beginning of summer due to the increase in glycol temperature during pipeline pumping operations. Vibration levels of the pumps and motors were measured over the whole speed range of the VFD during commissioning and were further monitored at normal operating flowrates. Vibration levels remained very low.

CONCLUSION

A high viscosity hydrocarbon was successfully pumped in an insulated pipeline with regular pipeline pumps by heating and maintaining high temperatures through the pipeline. At the elevated temperatures, the viscosity of bitumen is similar to other heavy crude pipelines and can be pumped with centrifugal pumps. The consequence of an extended shutdown of the pumping station and pipeline would render the pipeline unusable due to the hardened bitumen linefill. Therefore, a large effort and cost went into ensuring the equipment was properly selected, spared, and protected. Backup and redundant systems allowed for recovery from numerous failure scenarios.

Unique features of the project included the need to pump hot bitumen and to keep the bitumen heated in the pumping equipment, even in idle units. The remote location for the pump station, difficult weather conditions, and high construction costs led to the decision to fabricate the pump station in steel structure modules 500 km (315 miles) away in Edmonton, Alberta, and ship them to site for assembly. Piping expansion loops, spring supports, and skid bases were engineered to minimize stress on the pump nozzles. The pump station is designed to operate unattended with automatic control and protection monitoring from a local PLC and control center in Edmonton, Alberta.

The pump station and pipeline started on November 1, 2001, and have operated successfully to date. The pumps are running reliably with little required maintenance.

The authors' company has shown that it is possible to reduce reliance on and costs of an ever increasingly scarce diluent by pumping bitumen over long distances without the need for diluent. This can further open up development of the vast oil sands deposits in Northern Alberta.

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