ABSTRACT

A major U.S. pipeline company was experiencing multiple problems at a crude pipeline intermediate pump station:

- Pipeline pumps were rated for 3500 to 7000 bph on 20 cSt crude (original design).
- Reliability and mean time between repair (MTBR) problems on existing centrifugal pumps because of operating at about 600 bph
- Viscosities ranging from 1500 cSt to 5000 cSt (versus original design)
• The installed pumps also were under a power company restriction of 500 hp maximum (because of inrush current limit at starting conditions).
• The required flow rates varied from about 425 bph to 800 bph.
• Because of viscosity correction the centrifugal pump efficiency varied from about 10 to 20 percent when MTBR allowed the pumps installed to run.
• Pressure management on the pipeline system was not evenly distributed between the stations.

The application seemed ideal for a rotary positive displacement (PD) pump. However, there was an additional complication/concern because only a few company personnel had experience with operating positive displacement pumps in series on a “tight-line” operation.

The pipeline company’s personnel worked with vendors to select a probable pump. The selected vendor provided several pipeline companies as reference examples of running rotary PD pumps in series across a pipeline system. After observing firsthand the operation of a pipeline system in Canada, the company then used computer simulations to model the hydraulic responses of the pump, controls and pipeline system. The computer simulations convinced management that rotary PD pumps would indeed function properly and safely in series with reciprocating PD pumps that were located at the originating pipeline station (upstream in the system).

Additional items that were addressed as part of the redesign of the station were:
• Equipment vibration level reduction.
• Flow-rate flexibility and control system upgrades for the system and redesigned station.
• Electrical distribution stability for the station.

Once installed, the rotary PD pumps provided improved MTBR, better pressure management, and more cost effective operation of the pipeline system in question. The throughput increase averaged 39 percent even though the increased power cost was only 9 percent.

The tutorial will show examples of:
• Operating data showing system flow before and after station redesign.
• Rotating equipment installation improvements using before and after photos.
• Operating data showing pressure management improvements.
• Station operating costs before and after and cost per barrel improvements.
• Pump testing and inspection to ensure minimal startup issues.

INTRODUCTION

Within the U.S., and probably worldwide, piping systems, pipelines and the pump trains that provide the flow within these systems have seen fluids with ever increasing specific gravity and viscosity.

Pipelines systems intended to meet the increasing demands of World War II and the increasing demands of North American consumers in the postwar era, often were designed for flow of 5000 bph to 20,000 bph ± on crude oil of 20 cSt to 50 cSt. However, these pipeline systems found operating flows declining by the last decade of the 20th Century and in many cases conditions in the early 2000s found flow at 10 percent to 20 percent or original and viscosity 100 to 200 times higher.

This tutorial encompasses:
• A decline from a design of ~7000 bph to ~700 bph.
• An increase of density from ~0.85 to ~0.93.
• An increase of viscosity from 20 cSt to 3000 cSt.
• How is this fluid cost-effectively pumped at the desired flow?
• How is MTBR optimized?
• How can all the above be done and operate safely (i.e., operate within 49CFR195)?

Refer to Figures 1 through 4.
operation of a “series PD pipeline” prejudiced my thoughts of how this operational method). Suffice it to say, participating in the station was operating at approximately 1000 bph. In 1998 the flow rate had further declined to 700 bph. Viscosity and density had increased such that station discharge pressures were nearly identical to initial 1950 design at the lower flow rates.

Kirby pump station had two pumps. Pump #2 was 4×6×10 pump with four stages and a best efficiency point (BEP) of about 3500 bph and Pump #1 that was a 6×10×19 two-stage double suction first stage with four stages and a best efficiency point (BEP) of about 1570 bph. Pump #1 had issues of maximum temperature. By 1985 the station was operating at approximately 1000 bph to 7000 bph for crude oil that was about 20 to 30 cSt at ambient temperature. As time passed from 1950, the input station upstream of Kirby Station was converted to only reciprocating, positive displacement pumps. The pumps at the Kirby Station and the Lost Cabin Station (next station downstream) remained centrifugal pumps. As flow rate declined and density and viscosity increased, the efficiency of the centrifugal pumps dropped. Operating costs increased but not sufficiently to financially justify the replacement of the centrifugal pumps with rotary PD pumps purely from operational savings. Many pipeline company personnel had considerable reservations about the real feasibility of running PD pumps in series while operating a pipeline in a “tight-line” manner.

So let us digress to a time before your presenters today were born, even before I was born! In the 1940s and early 1950s, crude pipelines often operated with PD reciprocating pumps. Operators for pipelines with all PD pump stations would get on a phone line called a “ring down circuit” (a.k.a. “party line”) and would start up pipelines often operated with PD reciprocating pumps. Operators for pipelines with all PD pump stations would get on a phone line called a “ring down circuit” (a.k.a. “party line”) and would start up the pipeline system by watching station incoming pressure and bringing the variable speed, diesel driven, pumps up to speed when pressure increased to about two times required pump suction. This operating method prevailed until the 1970s in many locations. (Fortunately, I was a novice engineer at the extreme back end of this operational method). Suffice it to say, participating in the operation of a “series PD pipeline” prejudiced my thoughts of how to handle high viscosity crude. Faced with:

- Pipeline pumps were rated for 3500 to 7000 bhp on 20 cSt crude (original design).
- Reliability and mean time between repair problems on existing centrifugal pumps because they operate at about 700 bhp.
- Viscosities ranging from 1500 cSt to 3000 cSt (versus original design).
- The installed pumps also were under a power company restriction of 500 HP maximum (because of inrush current limit at starting conditions).

The pipeline company’s and engineering, procurement, construction (EPC) engineers involved tried finding ways to make the existing centrifugal pumps work, but efficiency and MTBR were unacceptable. The engineers requested several major U.S. manufacturers of centrifugal pumps to “look again” at possible selections, but it just was not possible to put a square peg in a round hole. The viscosity was so high and the flow range was so low that performance predictions approximated educated guesses. Performance testing on water would not provide realistic indication of performance at rated viscosity and therefore performance guarantees and three-year API run times were thought impossible.

Finally, with no real options left, some more experienced engineers convinced a few others and one brave systems programmer to try to model the proposed operation with rotary PD pumps in series. The model showed that the system was stable when adjustable speed drives (ASDs) (a.k.a. variable frequency drives [VFDs]), flow recirculation, and pressure relief valves at downstream stations were properly applied. One supplier replied to a request for users who possibly had systems similar to the one that was modeled and we began the task of redesigning the pipeline station and operation.

DESIGN PROCESS

It was understood that the following could not be changed:

- MAOP could not change from 1150 psi (825 to 875 discharge at average flow)
- Flow rate range had to remain 400 bph to 800 bph (typical 700 bph)
- Viscosity range was 1500 to 3000 cSt
- The local power supplier would not allow more than 400 hp motors with across the line starting because of inrush current possibly causing “flicker” or voltage dip during pump/motor start-up.

It was necessary to determine if the pipeline controls could react properly with the proposed rotary PD pumps. Therefore a hydraulic simulator was programmed with two rotary PD pumps that were controlled by ASDs and that controlled the following:

- Station discharge pressure
- Pump suction pressure
- Pump horsepower
- Pipeline flow rate

It was assumed that normally the controller would control on the pump suction parameter. However, there was concern that an upset requiring a rapid control shift from pump suction to some other parameter—probably station discharge pressure but possibly horsepower—could occur. The primary concern with these parameters was that one would “fight” another and the
pump control system at the station would go out of control and overpressure the station piping or downstream pipeline.

There was also concern that if an immediate stop was issued to the pump controls the bypass and relief piping could not respond rapidly enough to prevent overpressure of station piping. Figures 5, 6, and 7 show, respectively, piping and instrumentation drawings of the controls for one pump, the API 676 recommended control for a single pump, and the control for the entire station. Because the station is pigged 25-30 times a year, several tests and surge analyses were modeled and tested for automatic pig detection and shut down.

Figure 5. Kirby Rotary PD Pump Units PID.

As the process of building a computer model began, fact finding trips were planned to several companies already using similar pumps and control parameters. The plan was to observe as many normal pumping unit start/stop sequences as possible without requesting the host companies to perform immediate stop operation of the pumps.

Figure 7. PID for the Station.

Predicted design data was taken for the rotary PD pumps and that data was input into the model that had most of the PID information noted in the previous figures and those data were plugged into the pump data (Figure 8).

Figure 8.

The spreadsheet (Figure 9) shows the impact of fluid viscosity on the pump input horsepower required. The input energy required by the centrifugal pumps increased significantly with viscosity. The horsepower required by the rotary PD pumps was much more stable, for some viscosities even decreasing.

Figure 9.
FOUNDATIONS AND BASEPLATES

The best hydraulic design can still produce an installation that operates at less than optimal MTBR if the soil conditions, foundation, and baseplate are not well designed. Figures 10 through 14 show how the site was prepared and the foundation and baseplate were designed to optimize MTBR as well as how the baseplates were located on the foundation.

Figure 10.

Figure 11.

Figure 12.

Figure 13.

The baseplates were shipped with no equipment mounted. The foundation surfaces where epoxy grout was to be installed were scarfed. The baseplates were then lowered into position on the foundations, leveled, and grout was poured and cured for 48 hours. The equipment was then placed and aligned.

Photos of the finished station, showing layout and protective monitoring equipment are shown in Figures 15 through 23.

Figure 14.

Figure 15.

Figure 16.

Figure 17.
The pipeline company chose to purchase a major repair kit as shown in the Unit cross section drawing in Figure 24 and material list in Figure 25. To date there have been no repairs required for the two pumps installed and operational in October 2007.
MAINTENANCE AND UNIT AVAILABILITY

The units described in this tutorial have been operational for three years. Seals and bearings are still those installed at the original equipment manufacturer’s (OEM’s) plant. The units do have periods of unavailability but 95 percent of the time not available is attributable to electrical issues such as surges that trip the AFDs or cause motor operated valves to stop in transit. The station also shuts down automatically each time a pipeline cleaning tool passes.

CONCLUSION

Table 1 shows the operating statistics for the subject pumps and system. As can be seen, the system is operating ~39 percent higher throughput with ~9 percent additional power cost. This a net of ~30 percent flow increase for the same power cost. The main reason that the power cost is not lower is due to electric company demand charges. The new pumps are so reliable that they run nearly continuously. Maintenance costs have declined to approximately one-fourth of the centrifugal pumps. When crack spread, maintenance cost, and power costs are summed, it is estimated that the installation paid for itself in about two years.

Table 1. Power Cost and Shipping Cost/Barrel.

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Total | 131,14 | 145,727| 123,178| 40,013 |
Average| 11,07 | 12,74 | 11,36 | 10,01 |

Invert 11,07 | 12,74 | 11,36 | 10,01 |

Table 1. Power Cost and Shipping Cost/Barrel.