CUSTODY BATTLES

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explains the process of custody transfer on the world's longest heated and insulated pipeline.

Figure 1. *Metering stations were installed at each refinery along the pipeline.*

The discovery of oil in the Mangala region of Rajasthan, India, in 1998 is helping make India less dependent on imported oil. The field contains an estimated 3.6 billion bbls of oil. To date, Cairn India Ltd, a private energy company, now part of the Vedanta Resources PLC Group from London, has drilled more than 100 wells. Production began in 2008. Peak production is expected to reach 265 000 bpd, worth about US$ 7 billion/yr at approximately US$ 73/bbl., and representing 20% of India's oil production.

A major challenge in system design is the nature of the oil being transported. The viscous oil has an API gravity between 25 and 30 and it is waxy, becoming solid at room temperatures of 25 °C. Its pour point is 38 – 42 °C, compared to light crude at 3 °C, with wax appearing at 64 °C.

To solve the problem of transporting the waxy, high pour point oil, the company had to construct the world's longest heated pipeline (Figure 2). This pipeline provides oil to multiple refinery customers throughout the country and thereby accesses markets en route. Spanning 680 km and employing over 11 000 skilled labourers, Cairn successfully completed the pipeline and achieved initial production within five years.

The heated and insulated pipeline carries oil from wells in Mangala's oilfields to six refineries on the western coast of India, including Reliance refinery, currently the largest refinery in the world. Heaters and insulation are designed for temperatures of 90 °C.

With the pipeline infrastructure in place, the next big challenge was to figure out how to analyse and properly measure the amount of product transferred to buyers. After a bidding process, Cairn chose Daniel Measurement and Control to provide a complete metering solution.

Metering heavy oil

With the guidance of Daniel, Cairn chose to install fully engineered, integrated and pre-packaged custody transfer metering skids with ultrasonic accounting flow meters at each of the customer's terminals (Figure 3). These skids would be the final measuring point for transferring the crude directly to the client, thus ensuring the highest level of accuracy and repeatability.

One of the advantages of ultrasonic meters is that they are full bore and have no mechanical parts to wear or foul inside the pipe, which provides for low pressure drop, increased energy savings, and maintenance-free service. Conventional flow meters such as positive displacement, and turbine meters have moving parts and require more maintenance.

Daniel designed each metering station to Cairn's requirements and in full compliance with the API Manual of Petroleum Measurement Standards (MPMS). Because Mangala crude is very waxy and has a high pour point, it is rather challenging to measure, but the design philosophy was that there would be no compromise in fiscal measurement performance of the crude oil transaction between Cairn Energy and its customers.

Sizing of individual components, the selection of the proving technique and the proving philosophy, and implementation of each metering station with full heat tracing and insulation ensures the temperature of the crude oil is maintained far above the pour point at all times during the flow. And during any no-flow conditions, the system has the flexibility to increase the temperature to prevent wax formation.

Daniel employs an integrated engineered system process, which designs the customer solution using a 3D scale model. This model is developed from the approved P&IDs (Figure 4).

This 3D model helped Cairn review the desired measurement solution ahead of time at various stages of the project, and thus allowed Cairn to implement changes to the system design with ease.

It also helped Cairn review the complete bill of materials for manufacturing and perform engineering reviews on the general arrangement, stress analysis, centre-of-gravity calculations and other factors.

Each skid contains Daniel multi-path transit-time liquid ultrasonic flow meters, Daniel compact provers and S600 flow computers, Micro Motion density meters, Rosemount pressure and temperature transmitters, control valves from Fisher, EGS heat tracing and power distribution and junction boxes, and other required components.

The 3D design methodology is integrated into the manufacturing process to reduce lead times for such large infrastructure projects with aggressive project schedules. The skids were built at a triple ISO Certified custody transfer metering facility in Singapore.

The skids are large, heavy structures and were shipped by ocean cargo vessels to the entry ports in India. From there, they were trucked in country to the terminal sites for installation at the point-of-sale (POS). These pre-manufactured skids were shipped and installed as integrated packages.

Upon arrival at each refinery, the metering skid (Figure 1) was lifted by a crane and placed into position between the pipeline and the refinery. The metering skid solution that was delivered fit Cairn's needs, with metering and auto sampling systems all in one package. It was also relatively compact, and easily installed at each customer's premises.

Once the metering systems were installed, Daniel provided Cairn employees with the proper training and support in preparation for start-up and commissioning.

Custody transfer

All oil sold to each refinery is transferred by Cairn through a point of sale (POS) Custody Transfer Metering System (CTMS). Data from the CTMS forms part of the financial transaction. The CTMS includes custody transfer or accounting ultrasonic meters, a proving circuit for the verification of the accounting meters, and an auto-sampling system with a verification module for quality measurements, and a flow computer. In addition, a water-draw set up is incorporated to verify the compact prover as required. As per API MPMS, a water-draw is used to verify the performance of the prover when required.

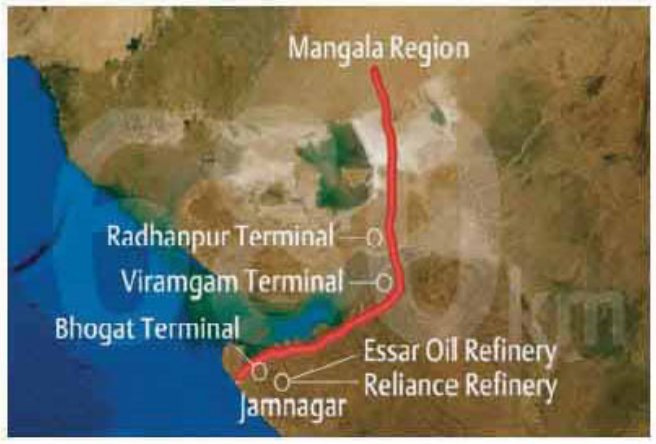

Figure 2. *A 600 km heated, insulated pipeline, the longest of its kind in the world, carries heavy, waxy crude from wells in the Thar desert to refineries on India's western coast.*

Figure 3. *The Viramgam terminal is one of six dispatch points along the pipeline.*

Figure 4. *The Daniel skid design software creates a 3D image of the metering station skid.*

Figure 5. *Each metering station has its own proving skid so that flow proving can be done in-situ at any time desired by Cairn or its customers.*

Since the crude oil comprises of base, sediments and water (BS&W), net fiscalisation is important to determine the final pure crude oil content in a sale. For this purpose, an online sampling system is provided that grabs crude oil samples on a representative basis. Cairn collects that sample in a can and performs laboratory analysis to verify the crude oil properties and BS&W.

The flow computer does flow computation of both quantitative (accounting meter) and qualitative (BS&W) measurements. It also performs computation of net fiscal amounts to establish the final quantity of crude oil sales, and this computation is provided with the required audit trail.

The calculations are implemented redundantly, and are performed in an audit trail environment. Similarly, each CTMS has one meter run that is redundant and acts as a hot standby should any meter run not be functional.

The flow computers, complete with the latest algorithms and software, allow for a fully automated system. All the flow computer measurement data is accessible over the Ethernet when required to provide up-linked system redundancy at multiple levels. In addition, the system is designed to provide flow measurement hardware redundancy with the design of multiple meter runs.

The accounting flow meters were wet calibrated in Daniel's flow laboratory in Houston, Texas. This wet calibration test determined each meter's flow calibration factor, also referred to as the K factor. After installation of the ultrasonic metering skid at the site, routine field proving is done as a means to establish the Meter Factor for the ultrasonic flow meter under actual operating conditions as per the requirements of API MPMS.

In addition to the initial proving, periodic provings are necessary to confirm or re-establish the performance accuracy of the accounting meter. The proving is done in accordance with API MPMS 4.2, 4.5, 4.8 and 5.8 recommendations. Field proving of ultrasonic meters for custody transfer is done in-situ, meaning the prover is placed in series to the accounting meter. Each of Cairn's metering stations has a built-in prover (Figure 5).

The basic concept of proving is to compare the known prover

measurement with the unknown measurement from the accounting meter under test. This is accomplished by having the accounting meter and the prover in series in such a way that all the fluid that passes through the accounting meter also passes through the prover. By measuring volume in this manner, Cairn is able to verify the accuracy of the ultrasonic meters as required by specifications, regulations and their customers' requirements.

During proving, crude oil is allowed to pass through the prover for some time until the flow rate, temperature, pressure and density stabilises. Once stability is achieved, the proving operations proceed. Daniel flow provers allow Cairn to verify the performance of the accounting meters to the requirements of API MPMS, and to obtain a repeatability of better than +/- 0.05% for five consecutive runs. This meter factor uncertainty is well within requirements.

After the proving is done and the results are obtained, the prover drain and vent are opened to release the fluid pressure and to drain the residual crude oil. When the prover is not being used, all power to the system is switched off, extending component life and saving energy.

Figure 6. *Accounting ultrasonic meter: Daniel Model 3804.*

Typically, a buyer and seller mutually decide how often they would like to see verification of the system in order to ensure confidence of the data. This data is a vital part of the commercial transaction. For the last year of proving since start-up, the company has not faced any issues with its customers.

Currently, offline diagnostics have been implemented via Ethernet connectivity between the meters and local diagnostic host. Routinely and when needed, these logs can be polled and emailed to Daniel service specialists for review to help identify if there is any impact on meter performance or health due to any external factors causing flow disturbance, clogging, pipeline noise, or other issues.

Cairn's long term goal is to move to online diagnostics. This would enable real time polling of data and performance verification of the accounting meters and other components when necessary.

Results

The company is pleased that liquid ultrasonic flow meters (Figure 6) have proven so successful in this very large scale measurement project, and that they are able to accurately measure a very difficult crude oil. The custody transfer system provides net fiscalised data that is field verifiable and traceable to the national standard of India. OT