Overland construction of the main pipeline for the Jorf Lasfar Slurry Pipeline in Morocco

The Jorf Lasfar Slurry Pipeline Project, Morocco

WINNER
International Projects Category

KEY PLAYERS

Client
Tekfen Construction, Istanbul, Turkey

Professional team
Paterson & Cooke Consulting Engineers (Pty) Ltd, South Africa

Main contractor
Tekfen Construction, Istanbul, Turkey

Sub-contractor
Raubicon Electrical Engineers and Project Managers

SUMMARY

The Jorf Lasfar phosphate slurry pipeline in Morocco, commissioned in April 2014, is the world's largest phosphate ore pipeline, with capacity to transport 38 million tonnes per year of phosphate ore for a distance of 187 km. It is the first substantial long-distance, high-volume slurry pipeline in Africa.

Due to the scale of the project the system comprises some of the largest slurry handling equipment yet produced. Innovations included the development of unique tools for the steady state and transient hydraulic design associated with transporting different grades of phosphate slurry in batches along the route.

The project demonstrates that slurry pipelines offer environmental and economic advantages when compared to conventional bulk materials alternatives, such as rail.

Paterson & Cooke Consulting Engineers (Pty) Ltd, based in Cape Town, was responsible for the overall hydraulic and process design, control philosophy, detailed piping and mechanical design of the head station, valve station and terminal choke station, construction assistance, operator training and commissioning management.

PROJECT DESCRIPTION

Morocco has been mining phosphate since the 1900s and is the world's largest exporter of the mineral. It accounts for approximately 30% of global trade in phosphate products. As part of an expansion programme to further develop the resource, the phosphate refinery and export terminal is being upgraded on the coast at Jorf Lasfar.

The feed to this facility is from the inland mining areas and the mineral was historically transported by rail. However, the rail infrastructure network operates close to peak capacity and cannot meet the increased demand of the new refinery. Various infrastructure studies showed that the most cost-effective bulk transport solution would be a 187 km slurry pipeline to the coast.

The phosphate transport system comprises a network of slurry pipelines from the different phosphate wash plants to a centralised head station at Khouribga. The product varies in grade and quality and is stored in separate agitated slurry tanks at the head station. The head station pumps the slurry for 187 km to the refinery in batches of different grades, interspersed with water to prevent cross-contamination of the material.

As these batches of phosphate slurry arrive at the terminal station they are diverted to dedicated storage tanks that feed separate process streams in the refinery to produce the different products.

The pipeline design needs to accommodate the different flow behaviour transport to ensure they are allocated to the appropriate tanks. This is achieved by controlling the pipeline operation by varying the pumping head, and through a series of pressure monitoring stations and a variable choke station at the terminal.

THE PIPELINE NETWORK

The head station receives phosphate slurry from the following feeder pipelines:

- 1 400 dry tonnes per hour from a 22 km, 450 mm diameter pipeline
- 1 500 dry tonnes per hour from a 15 km, 500 mm diameter pipeline
- 700 and 1 400 dry tonnes per hour from 2 km, 350 mm and 450 mm diameter pipelines respectively.

These pipelines automatically discharge different grades of slurry into designated storage tanks. Slurry flows from the agitated storage tanks to one of two mainline pump trains, each comprising six Weir Mineral 500 U-HTPP centrifugal pumps in series with 1 850 kW motors. Process water for batch separation, pipeline flushing and wash-down is via a 4.9 km gravity flow pipeline supplied by a 15 000 m³ reservoir.

The main pipeline is buried for the entire route and comprises a 900 mm diameter high-pressure steel pipe with a 22 mm HDPE internal liner to ensure that the pipeline can operate safely over the life of the mine. The pipeline is equipped with flow, density and pressure transmitters at the head station for flow measurement, batch tracking and leak detection. It is predominantly downhill, and has a capacity of approximately 4 400 t/h depending on slurry properties.

Due to the pipeline profile there is the possibility that the pipeline could operate in slack flow conditions if equipment and controls were not in place to prevent this. Slack flow occurs when the operating pressure in a pipeline is less than the atmospheric pressure, and free surface flow develops in the pipeline. In water pipelines it is common to install vacuum breakers or air release valves. However, this is not possible in a long-distance slurry pipeline. In slurry systems the presence of slack flow results in increased wear rates at the pipe invert as velocities increase due to the reduced flow area. In order to prevent slack flow it is necessary to ensure that the entire pipeline is pressurised, and this is achieved by using specially designed choke stations.

KEY DESIGN ASPECTS

A project of this nature has many challenges across all engineering disciplines. The key civil engineering aspects are related to the hydraulic design of the pipeline. This required a thorough understanding of the flow behaviour of the slurry. The development of a unique multi-species transient flow analysis tool allowed Paterson & Cooke to develop a robust control philosophy based on the steady state and transient events that could occur while pumping different grades of slurry.

Hydraulic design

The majority of long-distance slurry pipelines, such as copper- and iron-concentrate pipelines, transport finely ground ore with

The interior of the completed main pump station

Winner: Delighted representatives from Paterson & Cooke Consulting Engineers receiving their award from the 2015 SAICE and SAFCEC presidents (first and last from left respectively)

low viscosities. Phosphate ore, however, has a coarser top-size product with a substantial fine particle fraction that increases the viscosity. An exhaustive test campaign was completed at Paterson & Cooke's slurry test facility in Cape Town to determine the properties of different grades of phosphate.

As the batches are intermittent and have variable flow properties, the design accommodates a wide range of operating conditions whilst ensuring that the system remains within safe and reliable operating limits.

The operating envelope of the pipeline is bounded by:

- The heterogeneous turbulent deposition limits to ensure that coarse particles always remain in suspension during transport, and that the particle size is within the prescribed limits.
- The non-Newtonian transition between laminar and turbulent flow. Operation in laminar flow will result in segregation and settlement of the coarse fraction. This turbulent transition velocity (and corresponding flow rate) increases with solids concentration as the material becomes more viscous, and this requires controlling viscosity.

The control philosophy ensures that the following conditions are met:

- There is no slack flow at any point along the route.
- The velocity remains high enough to prevent deposition of solids.
- Slurry flow remains turbulent.
- The flow rate does not exceed the maximum limit.

Transient analysis

To limit pipeline wall thickness and reduce cost, the transient analysis considers water and slurry batches moving through the pipeline during various scenarios, for example, the transition of a water-slurry interface through the choke station or a pump trip during flushing with water in the pumps and slurry in the pipeline.

Paterson & Cooke uses a transient analysis software package, WANDA, developed by Deltares in the Netherlands. Paterson & Cooke contracted Deltares to jointly develop a multi-species transport extension for WANDA for the transient analysis of systems with multiple fluids of different densities and flow characteristics

(including non-Newtonian and mixed-regime slurry flow models). This extension also enables the analysis of control sequences to determine valve stroke rates, PID control settings and sequence timings to ensure safe startup and operation of the pipelines during commission and continued operations.

Terminal choke station

The pipeline profile means the system requires a choke station at the terminal. The choke station is designed to handle pressure of up to 10 MPa. The station has four choke loops, each with two ceramic orifice plates. Actuated slurry valves in each loop force slurry through the loop when closed, or allows the slurry to bypass the loop when open. The orifice plates are different sizes, and by utilising various combinations, the total choking head can be varied significantly to accommodate changes in operating conditions. These combinations are programmed into the SCADA system so that operators can select the degree of choking and the system automatically opens or closes appropriate valves.

CLOSING COMMENTS

A brief synopsis like this cannot do justice to the magnitude of this project and the various essential components of its chain.

Apart from the engineering being completed from Cape Town, the following South African companies supplied key components to the project:

- Mixtec South Africa, who supplied the 250 kW agitators for the fifteen ± 6 000 m^3 tanks.
- Urethane Moulded Products, the only company worldwide able to supply the precision urethane-lined 900 mm diameter steel pipeline's special bends and fittings.
- Blue Cube Systems (Pty) Ltd, a technology company focused on real-time in-line instrumentation for the minerals processing industry, who supplied the online analysers to determine the different grades of phosphate transported in the pipeline. □

QUICK FACTS

- The main pipeline required 50 000 tonnes of steel.
- The project took 1.7 million man days to construct.
- At the peak of construction 1 800 people and 800 construction machines were employed on site.
- The control system required more than 6 000 input/output signals that allow for a high degree of automation and safety.
- The installed slurry pump power at the head station is approximately 24 MW.
- Other interesting statistics as a consequence of the slurry pipeline include:
  - a 90% reduction in logistics costs
  - a 930 337 tons per annum reduction in CO_2 emissions
  - 3 million m^3 of water are saved every year.