STUDY OF A VIETNAM 155 KM BAUXITE SLURRY PIPELINE FROM THE HIGHLANDS TO COAST

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Abstract

Vietnam's bauxite resources are mainly found in the Highlands region, which is also home to the upper catchment areas of some of Vietnam's most significant river systems. The location of alumina refineries in the Highlands region with their associated residue disposal facilities raises serious environmental concerns. The tropical climate zone brings periods of intense monsoonal rainfall that needs to be contained and managed. The likelihood and impact of fugitive dust emissions, ground water contamination, or discharge of contaminated water streams must be minimized. The existing infrastructure for transportation of raw materials, refinery supplies and product alumina to and from the refinery is also limited. Therefore, potential investors will have to pay high costs to minimize the environmental risks and to upgrade and improve transport infrastructure in order to build and operate their refineries in the Highlands.

One potential solution to these problems is to locate future alumna refineries closer to the coast some distance from the mines and beneficiation plants in the Highlands. In coastal locations, red mud can safely be neutralized and stored using sea water and alumina product can easily be transported to a nearby port.

A Vietnamese alumina project has now been proposed to build a mine and beneficiation plant in the Highlands (Gia Lai province) and the refinery close to the coast (Binh Dinh province). The connection between the two plants will be via a 155 km bauxite slurry pipeline.

This paper describes the technical aspects of the pipeline design, operating and control philosophy, maintenance, and capital cost.

Nomenclature

Cw - Solids concentration by weight (%)
d_{50} - Particle size at 50% cumulative mass passing (µm)

1. Introduction

Various options have been considered for transporting bauxite from a proposed mine in the Vietnamese Central Highlands (Gia Lai province) to a refinery located 155 km away on the Coast (in Binh Dinh province). The options included overland conveyor, railway, trucking, and pipeline.

Overland conveyors would require several conveyors in series and would be subject to horizontal alignment restrictions. Conveyor costs are affected by terrain and security considerations and they are generally best suited to distances of less than 100 km.

Due to the rugged terrain that exists between the Highlands and the Coast, a suitable railway route would require an unsuitably long and indirect path, making the capital cost is unviable.

Large-capacity trucks are cost effective to transport, however they require broadening of roadways and upgrading of bridges to accommodate heavy duty uses.

The remaining option, a slurry pipeline, is a widely used, safe, cost effective and reliable way to transport minerals over long distances. Therefore, this option was chosen for the study.

2. Pipeline Design Considerations

***Water Supply*:** A reliable water supply is essential. A water storage reservoir may be required to guarantee water supply during the dry season. If there is a lack of water resources, then a return water pipeline would be necessary from the dewatering facilities at the refinery back to the beneficiation plant. A return pipeline would considerably increase the project cost.

Pipeline Throughput: The initial feed requirement of the refinery is 1.5 Mtpa of dry bauxite ore. However, to accommodate future production increases, the pipeline throughput is scheduled to increase in number of stages up to a maximum throughput of 3.25 Mtpa. The pipeline is operated in batch mode to achieve the lower feed rates at the start of the project.

Slurry Properties:

Particle Size Distribution. Finer particle sizes are required for long distance transport by pipeline rather than those are required for the digestion feed. The optimum particle size distribution for hydraulic transport is a balance between the beneficiation plant and dewatering facility costs.

The particle size distribution of the bauxite slurry is shown in Figure 1 with a d_{50} of 55 µm.

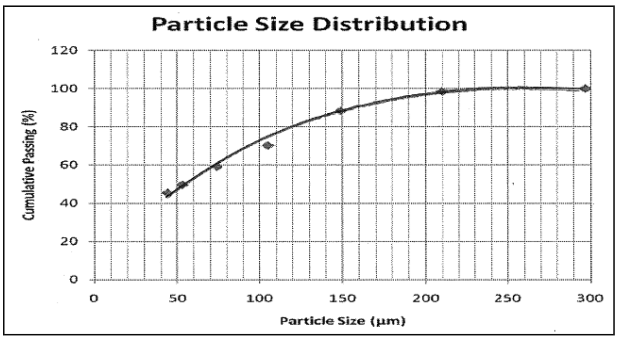

Figure 1: A typical particle size distribution.

- **Solids Concentration.** The higher solids concentration results in reduction of water transported with the solids but higher viscosity. Therefore the suitable range of solids concentration for this bauxite ore is 50-54% by weight. The slurry is dewatered at the refinery to achieve a moisture content of 12 - 15%.
- **Solids Specific Gravity.** The specific gravity of bauxite solids is in a range of 2.6 to 2.8.
- **Rheology.** Figure 2 shows that bauxite slurry behaves a Bingham plastic fluid.
  In the laminar flow regime, the pipe friction loss is dependent on the apparent viscosity. However, in the turbulent flow regime, turbulence effectively destroys the yield structure and therefore the apparent viscosity approaches the plastic viscosity.

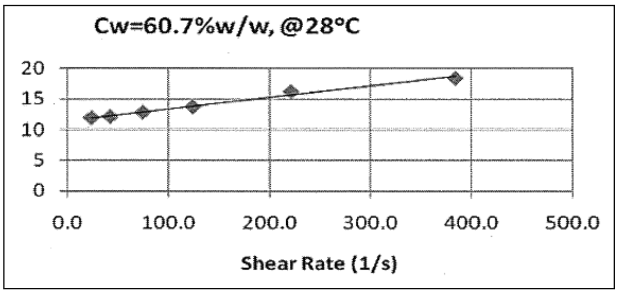

Figure 2: Rheograms of a Vietnam bauxite slurry

Pipe Route: Figure 3 shows the route of the slurry pipeline from Gia Lai province (highlands) to Binh Dinh province (coast). The route length and ground profile are basic parameters for the pipeline design. To minimise the capital cost a minimum length route is selected, however this is subject to the allowable slope of the pipeline and negotiations with landowners along the route. Where possible, the pipeline is routed across country, avoiding roads, rail and other infrastructure which impose additional design limitations and costs.

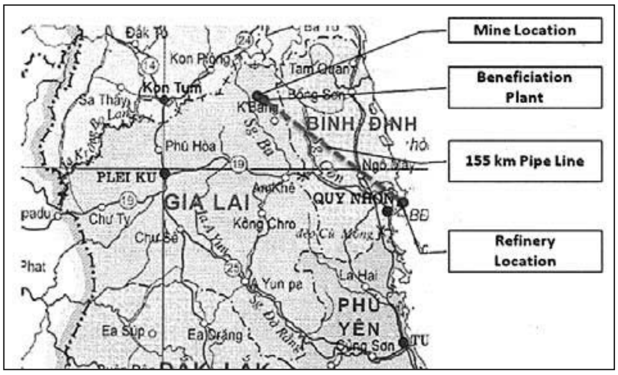

Figure 3: Proposed Pipe Route.

Climate Considerations: Vietnam is in a tropical region, therefore there is no risk of freezing slurry. However in cold climates where there is a risk of freezing (leading to pipeline blockage and rupture), the following options would need to be considered:

- Preheating of slurry
- Pipeline insulation and heat tracking
- Burying the pipeline below frost depth
- Use of anti-freeze in flush water
- Installation of emergency power for continued pumping
- Use of nitrogen or air at high pressure to clear flush water from the pipeline.

Environmental Considerations: Slurry pipelines are known for their environmental friendliness because of their safety record, and because after construction and restoration, the land through which they pass can be returned to its original use. Special consideration needs to be given to interference with land use during pipeline construction, construction of road, rail and foreshore crossings, and interference which may occur during future pipeline maintenance.

Corrosion and Erosion Rate: Chemical indicators such as pH, chloride, sulphate and dissolved oxygen are associated with water corrosion. Laboratory water corrosion tests should be performed to detect sources which cause corrosion such as chemical ions or bacteria. Many factors such as velocity, particle concentration, impact angle, particle characteristics and pipe characteristics are known to affect erosion. The erosion rate can be obtained from a pipe loop test.

Due to the lack of test information of slurry pipeline wear rate at this stage of the study, an average wear rate of 0.25mm per year is assumed for the pipeline.

Life of Pipeline: The pipeline is designed to operate for 30 years.

Codes: Australian Standards (AS) are used for the design. Other standards such as American Standards ANSI/ASME B31.11 and British Standards (BS) can also be used.

Dewatering: At the discharge point of the pipeline, water must be removed prior to the digestion process. Dewatering may be done mechanically via filter presses, centrifuge and screen. The efficiency of dewatering depends on the particle size distribution of transported slurry.

3. Pipeline System Design

The analysis of the pipeline system is performed using Hatch's in-house computer programs. The pipeline has a DN300 diameter pipe with an average wall thickness of 21.44 mm.

3.1 Hydraulic Analysis

Deposition Velocity: The minimum safe operating velocities for the pipeline are governed by the deposition velocities for the solids content considered for this project, 50-54%w/w. The correlations of Oroskar and Turian (1980), and Wasp (1977) modified Durand were used to estimate the deposition velocities The results are shown in Table 1.

Table 1: Estimated Deposition Velocities

Solids Concentration (%w/w)	Oroskar-Turian (m/s)	Wasp-Durand (m/s)
50	1.90	1.78
52	1.88	1.80
54	1.86	1.81

The Wasp-Durand correlation does not take into account the fluid viscosity therefore the deposition velocity increases as an increase of solids concentration. The Oroskar-Turian correlation was used in this study.

An underestimate of the deposition velocity will result in a partial blockage of the pipeline and an increase of the pump discharge pressure. One of the solutions for this problem is a reduction of particle size distribution from the beneficiation plant, however if the particle size is too fine then the slurry viscosity will increase.

The deposition velocity and other parameters can be verified from a pipe test loop. This information establishes the system pipe size, throughput and operation envelope limits.

Pipe Size Selection: Coarse materials require high transport velocities whilst fine materials require low transport velocities. Therefore pipe diameters are selected to achieve a design velocity which is a margin above the deposition velocity.

Pipeline Slope: A maximum slope restriction of 15% is applied to the pipeline.

Pump Selection and Station: Long distance slurry pipelines usually utilise positive displacement pumps to transport slurry due to high discharge pressure requirements.

The maximum allowable pressure for positive displacement pumps available in the market is 30 MPa.

A single pumping station located at the beneficiation plant is preferred due to security considerations. The pipeline design is selected so that these conditions are satisfied.

A pump system of 4 Geho TZPM2000 (three-duty and one-standby) with a maximum discharge pressure of 25.52 MPa is suitable for the pipeline.

Pipeline Profile and Hydraulic Gradient: Figure 4 shows the pipeline profile, hydraulic gradient and maximum allowable operating pressure (MAOP) for the initial and end of the pipeline life.

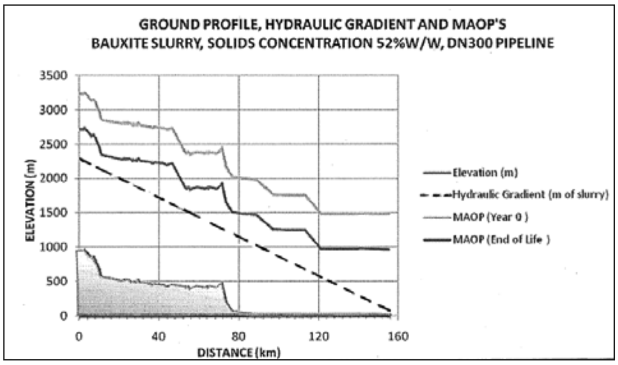

Figure 4: Pipe profile, Hydraulic gradient and MAOP's.

The pipe material is ANSI Material grade A106 B, carbon steel pipe. A design factor of 0.667 of the yield stress has been used for the design to comply with AS4041.The pipeline is designed to have adequate steel thickness to withstand the steady state slurry hydraulic gradient and static head when the pipeline is shutdown. The pipeline thickness is chosen so that the operating pressure range is within a safe envelope.

Potential Slack Flow: Slack Flow or Open Channel Flow occurs when the available static head between two points in the pipeline exceeds the friction loss between these two points at a given flow rate. An increase of slurry velocity occurs due to the conversion of potential energy to kinetic energy. To maintain mass flow, this increase in velocity requires a reduction in flow cross sectional area. Under slack flow conditions, a negative pressure exists in the pipeline and water vapour fills the upper segment of the pipe cross-section leading to "open channel flow'. Under theses conditions, high wear occurs due to the high velocities – this should preferably be avoided.

Due to high terrestrial gradients in the pipeline route, slack flow could potentially occur in this pipeline, Therefore 2 choke stations will be installed in the pipeline.

3.2 Pipeline Analysis

Operation Envelope: Figure 5 shows the system design operating envelope. The upper and lower limits of solids concentration and transport velocities define the operating envelope. The upper throughput is limited by the installed pump power as well as the velocity limit.

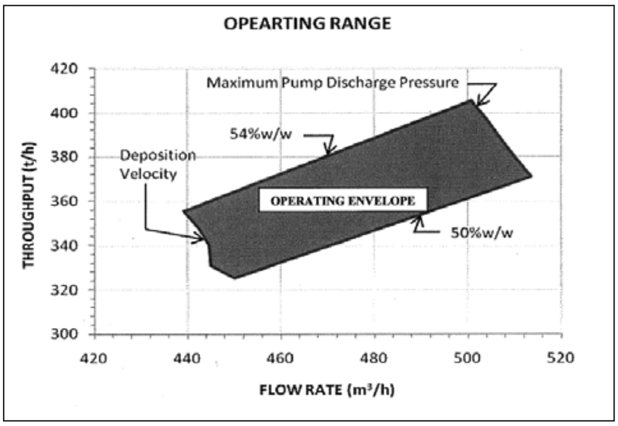

Figure 5: Design Operating Envelope.

Choked Station: Control of slack flow involves the addition of head dissipation devices to increase the system's friction loss. This can be accomplished by reducing the pipe diameter or by installing fixed chokes (orifices).These chokes can be installed in both a permanent in-line orientation and a bypass orientation. The combination of both types of chokes is useful where a large pressure dissipation requirement that is variable over the operation envelope.

The choke station design must also take into consideration the transient conditions which occur when the pumping operation is switched from slurry to water, water is switched back to slurry, and also system start-up and shutdown.

Transients: When a velocity change occurs in a flowing fluid some of kinetic energy is converted into pressure energy which produces a hydraulic surge or "transient". In pipelines, this can be caused by a delivery valve closure or pump start-up or shutdown. Slurry behaves differently from water but this problem can be significant and will be considered in the detailed design.

4. Operating and Control Philosophy

The fundamental design of the system will be such that normal short term capacity-control shutdowns will not occur more than once for any given batch of slurry. Short-term shutdowns do not require complete pipeline flushing.

The pipeline will operate within a specified volumetric flow range, above deposition velocities, below the maximum pump pressure and the pipeline velocity limit. Pressure monitoring stations will be installed along the pipeline at 40 – 50 km intervals.

The pipeline is controlled to maintain throughput between two process plants, beneficiation and dewatering plants. This throughput is controlled by monitoring process variables at the initial pump station. Other parameters that will be controlled in the pipeline are corrosion, slurry pH, slurry viscosity and particle size.

4.1 Pipeline System

Commissioning: Pre-slurry start-up activities will be followed by commissioning on slurry. The commissioning program is planned to demonstrate and prove system performance under operating conditions, shutdown and restart, pipeline flushing and pigging operations. The program is also used to train operators.

Leak Detection: The slurry concentration within the pipeline will be monitored by a leak detection system. Leaks are unlikely in a well maintained and operated slurry pipeline. Data including flow, pressure, density and temperature measurement at various points along the pipeline are used to continuously check for pipeline leaks.

Overpressure Protection: The pipeline and equipment will be protected from overpressure by several levels of protection. First by implementing proven operating procedures, then the use of computer system software, electrical or hardware interlocks or control loops, and lastly by mechanical pressure relief devices.

The locations, sizing and set points of mechanical pressure relief devices will be reconfirmed during the detailed designed phase through the use of hydraulic transient analysis. The final operational procedures such as sequence of station shutdowns, timing of valve operations, etc., will also be determined at that time.

Safety: The pipeline contains only non-flammable liquid-solids and does not pose an explosion risk. High pressure slurry is a non-compressible fluid but can be aggressively abrasive if a leak occurs. Operators will be instructed in the safe operation of the high pressure slurry pipeline. Additional design techniques and safety factors will be applied for all special design points such as thicker pipe wall at river and road crossings.

4.2 Operation

The slurry pipeline operates in a batching mode. Batching operation involves pumping accumulated slurry which has been stored at the beneficiation plant followed by online switching to pumping flush water. The flush water maintains a normal pipeline flow rate and prevents settling of slurry in the pipeline. However, it is possible to shutdown and restart after short periods with slurry in the pipeline, With confidence in this procedure, it can replace for the batching/flushing operation to minimise energy and flush water usage.

The most common cause of pipeline shutdown is power outage leading to pump shutdown and blockage in the pipeline. Therefore, the system must be capable of shutdown and restart with slurry in the pipeline. The pipeline is designed to restart within 24 hours.

4.3 Control

Pipeline: The pipeline operation requires a minimum level of direct control which can be performed as part of the existing duties of the beneficiation plant operators. Pump station instrumentation monitors and controls key operating variables. Slurry batches are pre-tested to check if slurry is within pipeline specification. If the test results are within specification, the batch is acceptable for pumping. Off-specification slurry is a danger to pipeline operation.

Corrosion: Monitoring and control of pipeline internal corrosion is required to ensure long life of the pipeline. Corrosion control involves a program of controlling corrosivity of the slurry for day-to-day operation and to monitor the long-term corrosion in the pipeline. Slurry pH is kept in a range of 9 to 10 by adding lime or caustic.

The outside wall of the pipeline is painted and cathodically protected from corrosion. The test points which are installed along the pipeline route during construction are spaced at approximately 2 km.

4.4 Maintenance

Pumping Station: Pump station operating equipment is regularly inspected. An effective and efficient preventative maintenance schedule is applied to increase total system availability of 99%. Positive displacement pumps are subjected to vibration therefore fatigue failure in valves, pipe supports and fittings is considered in the detailed design.

Pipeline: It depends on local conditions, the pipeline is designed with a combination of underground (in pipe culvert) and aboveground routing. The pipeline right-of-way is regularly inspected at approximately monthly intervals or weekly intervals in seasons of severe weather.

Pigging: Small corrosion pits develop on the pipe wall will increase in pipeline roughness. As a result, pump discharge will gradually rise. The slurry pipeline is proposed to pig at 12 - 16 week intervals.

5. Capital and Operating Costs

Capital Cost: The pipeline cost estimate was based on the government regulations and market labour in Vietnam for this 155 km bauxite slurry pipeline.

The estimate cost includes the design, procurement, material, equipment, construction, management and commissioning. Major cost components are tabulated in Table 2 below.

Table 2: Capital Cost.

ITEM	COST (USD)
Design	12,750,000
Material and Equipment	112,100,000
Construction	66,400,000
Others	4,050,000
TOTAL	195,300,000

Table 2 shows the capital cost for the pipeline is USD195.3million or equivalent to USD1.26million/km.

Operation and Maintenance Cost:

The operation and maintenance costs were based on the government requirements for the development of a new project and wage rates in Vietnam.

Table 3: Operation and Maintenance Cost.

ITEM	COST (USD)
Operation	4,370,000
Maintenance	3,000,000
Depreciation (assumed linearly)	6,510,000
TOTAL	13,880,000

Table 3 indicates that the cost for bauxite transportation by pipeline at capacities of 3.25 Mtpa is USD4.27/t.

6. Risks in Pipeline System

The following risks need to be addressed in operating a slurry pipeline transport system.

An increase in slurry viscosity or partial blockage due to an increase of particle size can result in an increase of hydraulic pressure.

The pipeline may be subjected to wear if there is a change in ore characteristics or a change in slurry chemistry due to bacteria in the water supply which accelerates corrosion. This will shorten the pipeline life.

Plugging is possible if the pumps stop for more than 30 minutes for certain particle sizes.

If the slurry particle size distribution is too fine, it increases slurry viscosity and affects dewatering plant filter operation and plant start-up.

7. Conclusions

Transporting bauxite slurry by pipeline may be the preferred solution over transporting dry bauxite or alumina by rail or truck from the Vietnamese Highlands to the Coast. However, there are number of risks as mentioned in this paper.

This analysis was based on the government requirements for the Feasibility Study in Vietnam. Much detailed analysis is required before the implementation of the project.

8. Acknowledgment

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