Case History

Baroid Industrial Drilling Products

Successful use of TUNNEL-GEL® for Construction of 5,050 m of Tunnels for 500,000 m^3/d Desalinization Plant, Magtaa Algeria

Project Owner— Algeria Energy Company (AEC)

Primary Contractor—Hyflux Singapore

Project Objective— Construction of four 3.0m diameter concrete Tunnels for inflow and outflow to Desalinization plant. Tunnel lengths 3 x 1,280m intake and 1 x 1,210m outflow

- **Challenges**
  - Brackish and fresh make-up water
  - Tunneling 13m beneath ocean bed into saline water which adversely affect slurry fluid properties
  - Tunneling in medium—fine grained weakly consolidated sand and sections of water sensitive marine marl
  - 2 bar water pressure
- **Equipment** - Herrenknecht AVND 2500 TBM. 3,025 m

Geology and Slurry Design Considerations

Onshore and offshore boring logs indicated medium – fine grey sand with scattered shells and levels of gravel as the primary geology type to be encountered in all four drives. Additionally the boring logs suggest the presence of Marl in the drive path (extent of Marl was unknown). Porous unconsolidated sands tend to allow the transfer of water based on pressure gradients and as such can be prone to instability and collapse during Tunneling. As such building and maintaining a slurry with good filtration control, <15ml/30min for cutting face and <10ml/30min for annular lubrication was key. Other design considerations include building/maintaining low mud weight with yield point in range of 10-14 lb/100 ft^2 so that slurry does not impede cuttings transport. O&M of Herrenknecht solids control (shale shakers/desanders/desilters) was critical to slurry mud weight and sand content control.

Slurry Design

Cutting Face

Soda Ash	1.0 kg/1000L
TUNNEL-GEL	30 kg/1000L
QUIK-TROL GOLD	0.5-2kg/1000L

Lubricating Slurry

Soda Ash	1.0 kg/1000L
TUNNEL-GEL	40 kg/1000L
QUIK-TROL GOLD	0.5-2kg/1000L

Geology and Slurry Design Considerations Contd.

QUIK-TROL GOLD was primarily used to improve the filtration characteristics of the slurry, but it's secondary function as a clay/shale inhibitor could be exploited when sections of Marl were encountered.

Contingency products **N-SEAL** and **DINOMUL** were available if slurry losses in gravel or annular friction became problematic.

The ground water chemistry data indicated high calcium (227mg/L), magnesium (261 mg/L) and total Hardness (1644 mg/L) concentrations and a pH -8.0.

Slurry Properties

Mud Weight	1.02 -1.03 SG (target <1.10)
Funnel Viscosity	40-45 sec/qt
	60-80 sec/qt annulus
Plastic Viscosity	8-10 cps
Yield Point	10-14 lb /100 sq.ft.
Gel Strength	10+ @10sec/25+@10min
Filtration	<15 mL/30min
	<10 ml/30min annulus
pH	8.5 – 1)
Total Hardness	< 100 mg/L

Slurry Mixing

Separate tank farms were available for building and maintaining the face and annular lubrication slurry. Water was pretreated with 1 kg Soda Ash per 1000L in order to help buffer slurry against hard seawater to be encountered. **TUNNEL-GEL** was mixed using a high shear venturi mixer for a minimum of 15 min before addition of **QUIK-TROL GOLD** to ensure proper bentonite hydration. Slurry viscosity and filtration rates were monitored to validate additive addition rates.

Slurry Testing Frequency

Slurry Test	Units	Testing Frequency		
		New Slurry	Circulated Slurry every 2 hrs	Annulus Lubrication Slurry every 2 hrs
Mud Weight	SG	x	x	x
Funnel Viscosity	sec/qt	x	x	x
Sand Content	%	x	x	x
Filtrate	ml/30min	x		x
Cake Thickness	mm	x		x

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Slurry Maintenance and Solids Control

Equipment employed included, shale shakers followed by desander and desilting cones. Solids entrained in the Slurry during Tunneling operation can negatively impact fluid properties. Routinely measuring and recording slurry properties, enabled Hyflux and Herrenknecht engineers to identify deficiencies and modify the slurry accordingly. Initial penetration rates generated a volume of solids which overwhelmed the solids control equipment and resulted in excessive mud weight and sand content (see data in Red). As a result, additional solids control equipment was added.

Example of Slurry test data. Green indicates data within min/max property range. Red indicates outside recommended property range. Managing the entrained fine solids was initially challenging due to the rapid penetration rate beneath the dunes section.

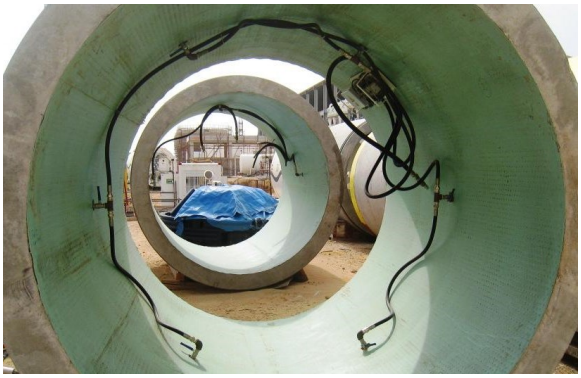
	Min.	Max.									
Sample From			Fresh Mud	Feed							
Date				2/6/11	2/6/11	2/6/11	2/6/11	2/6/11	2/6/11	2/6/11	2/6/11
Time Sample Taken				7:44	11:40	12:16	13:40	15:00	16:00	17:10	21:10
Pipe #				10	before 11	after 11	12	before12	before12	after12	after12
Weight (SG)	1.03	1.10	1.03	1.15	1.1	1.19	1.19	??	??	1.24	1.12
Funnel Viscosity (sec/qt)	37	60	44	44	39	57	49			48	36
Filtrate API (ml/30 min)	<10	<15	14	8.9	12	13.3	13.2			19	17
Cake Thickness (mm)	1	4	1	-	-	-	-	-	-	-	-
Sand Content (% by Vol)	NA	2	<0.5	10	6	20	16	9	5	10	4
pH ☑ Strip	8.5	10	9.-5-10	11	11	10	10			11	11
Total Hardness as Calcium, r	NA	100	<100	120	50	-	-	-	-	-	-

	Min.	Max.								
Sample From			Fresh Mud							
Date				10/6/11	10/6/11	11/6/11	11/6/11	11/6/11	11/6/11	11/6/11	11/6/11
Time Sample Taken				16:20	22:15	1:30	4:25	5:41	9:35	10:00	11:00
Pipe #				AF21	BF22	BF22	BF22	BF22	BF22	BF22	BF22
Weight (SG)	1.03	1.10	1.03	1.17	0.96	0.4	1.3	1.02	1.06	1.06	1.03
Funnel Viscosity (sec/qt)	37	60	44	30	35	31	60	56	53	45	45
Filtrate API (ml/30 min)	<10	<15	14	15	15	15	10	11	13.2	13.8	12
Cake Thickness (mm)	1	4	1								
Sand Content (% by Vol)	NA	2	<0.5	0.5	1.5	1.5	1	1.5	0.5	0.5	0.5
pH ☑ Strip	8.5	10	9.-5-10	8	7	7	10	10	8	8	8
Total Hardness as Calcium, r	NA	100	<100	-	-	-	-	-	-	-	-

Challenges and Solutions

Jacking Force - The anticipated jacking forces ranged from 200-500 tons. Some sections of each drive encountered significant zones of Marl, a water sensitive marine clay and jacking forces periodically would reach 800 tons. **DINOMUL,** a liquid wax based lubricant was added at 2-15 L/1000L to the lubrication slurry and injected via Ports shown below to reduce jacking forces.

ROP - Rates of Penetration ranged from ~10 m/d up to a maximum of 36 m/d. Reduced penetration rates typically occurred when encountering extended sections of Marl. The cutter wheels, designed for sand/rock, were subject to "bit balling" where clay adheres to cutting surface reducing the ability of the TBM to advance. Crews were instructed to raise the concentration of **QUIK-TROL GOLD** to 2Kg/1000L and add a wetting agent (**PENETROL**) at 1-2L/1000L.



Performance and Economic Benefit

- **TUNNEL-GEL** based cutting and lubrication slurry facilitated the successful installation of over 5,000 m of inlet and outflow tunnels for a 500,000 m^3/d desalinization plant in less than 18 months.
- Maximum penetration rate achieved 36 m/d. Equivalent of 12 x 3 m pipe sections. Average penetration rate 12 m/d.
- Lowest jacking force, 250 tons (geology fine sand/shells). Highest jacking force 850 tons (geology Marl/sandy silt).
- Contingency slurry additives **DINOMUL** and **PENETROL** resulted in improved penetration rates estimated to have saved 16 days of TBM time.
- **TUNNEL-GEL/QUIK-TROL GOLD** based slurry demonstrated a good buffering capacity (resistance to degradation) against seawater with significant hardness (1644 mg/L) and concentration of divalent cations (Ca^{+2} 227mg/L and Mg^{+2}261 mg/L).