BUILDING THE WORLD'S LONGEST HEATED PIPELINE A TECHNOLOGY APPLICATION REVIEW

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Abstract – The world depends on oil for much of its energy needs and global demand for oil is forecast to increase significantly in the future as countries such as China and India continue to develop [1]. Much of the world's conventional or "easy" oil sources have already been located and developed, so oil companies are increasingly turning to more difficult non-conventional oil sources which require innovative technology to be developed successfully. Often it is the physical properties of the oil that define it as non-conventional, such as being unusually heavy or viscous or containing a high percentage of wax, presenting difficult flow assurance and transportation problems that must be overcome. This paper describes the development of an Indian oil field containing an oil so waxy it is solid at ambient temperatures, requiring the construction of the world's longest heated pipeline to transport the waxy crude over 600km from a remote desert location to a coastal refining hub. The topics covered include the evaluation of various transportation solutions, selection of a skin effect heating system, thermal insulation, power sources and distribution, challenges associated with the design and construction, and lessons learnt that could enhance the safety and reliability of future projects.

Index Terms – Cairn India, flow assurance, heated pipeline, insulated pipeline, Mangala Development Pipeline Project, skin effect, waxy crude.

I. INTRODUCTION

In 2004 the largest onshore Indian oil discovery in 20 years was made when the Mangala field was discovered within the Barmer basin in the state of Rajasthan, North West India. With reserves estimated in excess of 1 billion barrels and potential production in excess of 200,000 barrels of oil per day it would equate to approximately 25% of India's domestic production. This was very welcome news for the energy security of a fast emerging global economic powerhouse with a billion strong population heavily reliant on imports for the majority of its oil needs.

There were many challenges, however. The Rajasthan crude oil was non-conventional. Classified as medium heavy with low sulfur, it had a high wax content of up to 38% by weight. The crude had a wax appearance temperature (WAT) between 50-65 degrees Celsius (°C), a pour point of between 32-42°C and a wax dissolution temperature above 80°C. These parameters mean that as the temperature of the crude drops below 65°C the wax begins to form a gel, and the crude becomes increasingly viscous as the temperature drops further. Below the pour point range the crude is effectively solid as indicated in Figure 1 and it must be heated above 80°C to re-dissolve all of the wax.

Fig. 1 Mangala oil at ambient temperature (inverted beaker)

It was obvious from the outset that transporting this waxy crude from the well to the refinery would present complex flow assurance issues and would be no ordinary project. Put very simply, the crude would not flow unless it was kept warm in every stage of its transportation. This would require a unique solution, the world's longest insulated and continuously heated pipeline.

The Mangala Development Pipeline (MDPL) project was conceived with the objective to transport stabilized crude oil from a processing facility located close to the remote town of Barmer in Rajasthan to the coastal oil refining center of Jamnagar in Gujarat. Not only was the 600km length a challenge, the pipeline also crossed 2 states, including 270 towns and villages, involved 40,000 individual land owners, crossed hundreds of roads, railways, major rivers and canals and was buried a minimum of 1 meter below the ground.

The MDPL project crude pipeline is made of carbon steel, 24" in diameter with a wall thickness varying from 10.6-14.3mm and a pressure rating of 90 barg. The pipeline has a Fusion Bonded Epoxy (FBE) corrosion coating, 90mm polyurethane foam (PUF) insulation, and an outer shell of 5mm high density polyethylene to protect the insulation and (crucially) prevent water ingress.

An 8" gas pipeline has been laid in parallel to the crude pipeline to fuel gas fired generators located at 35 stations located along the pipeline route.

With a budget of approximately US $1 billion and a workforce of over 5,000 the project was constructed in 23 months, with first oil flowing in June 2010. The pipeline has been operating since with a high degree of reliability.

A second phase of the MDPL project is due to be commissioned in 2014. This includes a pipeline extension of approximately 100km, an oil export terminal and a 12km marine pipeline to an offshore loading buoy.

A central aspect of the MDPL project was the requirement to ensure the crude oil was transported at a temperature not less than the wax appearance temperature of 65°C. After careful evaluation of all proven heating systems, it was decided to use skin effect technology as the most appropriate method [2].

II. MANGALA DEVELOPMENT PIPELINE (MDPL) PROJECT

A. Pipeline Alternatives

At the conceptual stage of the MDPL project, pipeline, road and train methods of crude transport were all evaluated as alternatives. However, given the volumes and risks involved, it quickly became apparent that a pipeline was by far the best transportation method. Consideration was also given to refining the crude close to the field location, but establishment of a new green field refinery was not commercially viable. Given the waxy nature of the crude, the technical focus shifted to considerations of pipeline heating and insulation.

B. Pipeline Heating Technology Options

Several heating methods were evaluated for use in the MDPL project. Methods used in the past by pipeline operators have included steam, re-circulating fluids (including hot water) and electric trace heating to provide a continuously heated pipeline. The use of chemical additives or blending the crude with another to improve the flow characteristics are other common options that could potentially reduce or remove altogether the requirement for heating, but the quantities of additive required for MDPL are prohibitive.

Steam heating has been in use for many years, but mostly for in-plant applications; it was considered unsuitable for MDPL. For long distance cross-country pipelines steam heating is not an ideal technical solution since it requires additional condensate return lines and other mechanical components that need frequent maintenance.

Hot water (or other suitable medium) based heating systems require a complex and costly pipe-in-pipe construction with numerous other special construction features.

Bulk heating of the product fluid prior to transportation by pipeline and at intervals along the pipeline route was also considered as it has been a common method for shorter distances and has been used successfully on other long distance pipelines. The advantage of this method is that the pipeline itself only has to be insulated, not heated. The key factor that ruled out this method for the MDPL was the fact that the Rajasthan crude will solidify at ambient ground temperatures, so if the flow stops and the pipeline cools it cannot be re-started. There have been examples of pipeline infrastructure rendered inoperable due to solidification of the product with no method of re-melting.

Different types of electric trace heating application methodologies have been deployed in the past to heat crude oil pipelines, including various types of conventional heating cables but these have relatively short circuit lengths and as such were unsuitable for the primary MDPL 24" pipeline. However, conventional self-regulating heat tracing was suitable and utilized at some of the shorter above ground piping segments at the 36 stations along the pipeline route.

Impedance heating is an electrical heating technology that involves passing alternating current (AC) directly through the pipe wall itself, creating heat through joule and hysteresis heating effect. Since voltage is a safety consideration it is normally limited to short pipe lengths in in-plant applications, again unsuitable for a cross-country pipeline.

Skin effect based trace heating systems have existed for more than thirty years with significant increased usage over the past 10 to 15 years. However, they had never before been implemented on a pipeline of this length, with the added complication that it was buried. Most applications of the skin effect heating in the past were for above ground applications and much shorter distances.

Skin Effect Heat Management Systems (SEHMS) as indicated in Figure 2 utilize a medium voltage wire (operating up to 4,000 volts in the case of MDPL) inside a carbon steel tube welded to the carrier pipe. The conductor and the tube are connected together to make a circuit up to approximately 10km long. The relationship between the tube size, the conductor size and the applied voltage determines the output power. The heat generation is based on the electrical phenomenon of Ohm's law, skin effect and proximity effect in ferromagnetic conductive materials under AC of commercial frequency.

Like heating cables, skin effect technology is very efficient since all of the heat is generated inside the thermal insulation envelope. The low impedance and high voltage capability of the skin effect heater enables it to operate over long circuit lengths at relatively high power.

After due evaluation of all potential technology solutions for the MDPL the project team concluded that skin effect was the most suitable system. It was recognized that it would require a number of innovations, additional analysis and testing plus new installation methodologies if it was to meet all the requirements of the MDPL project. While the basis for the technology was sound and it had been applied to many pipelines previously, no project had matched the scale and complexity of MDPL.

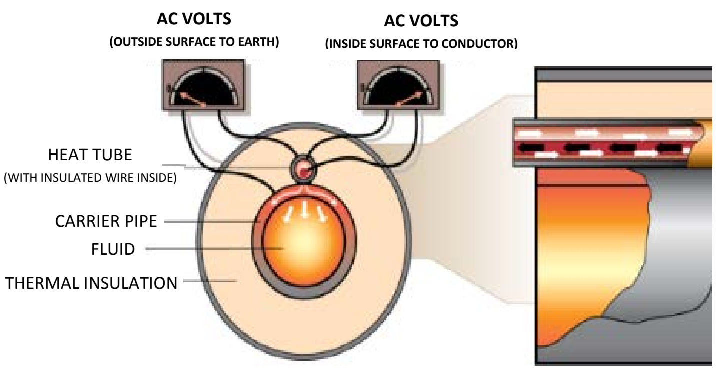

Fig. 2 SEHMS illustration

C. Thermal Insulation

Thermal insulation is a critically important element of the heating system. The SEHMS power input is calculated to replace the heat lost from the insulated pipeline to the surrounding environment, so for the heating system to operate as designed, the insulation must also perform as intended. Mechanical damage and water infiltration must be avoided as this will lead to a serious reduction in the insulation performance and potentially cause local cold spots leading to crude solidification. The risks associated with damaged insulation and water infiltration are higher for buried pipelines in comparison to above ground pipelines. An area of particular focus on the MDPL project was to ensure that the design was sufficiently robust for the environmental conditions but also such that constructability was not overly complicated.

Typical pipe insulation material options include:

- Calcium silicate
- Mineral wool fiber
- Fiberglass
- Expanded perlite
- Cellular glass
- Micro porous insulation
- Polyurethane Foam (PUF)

After a thorough evaluation of potential thermal insulation materials, including field insulation application considerations and project schedule and cost factors, the owners of the project decided to proceed with a pre-fabricated/pre-insulated piping technology utilizing PUF insulation. PUF has a superior k-value, high temperature performance, excellent mechanical strength, low moisture absorption and cost advantages over other insulation materials.

PUF with two densities were utilized for the project. A standard density was used for the majority of the pipeline route, but a higher density PUF, with greater mechanical strength, was utilized at locations where the pipeline was expected to be subjected to high stresses during installation and service. Figure 3 is a photograph of one of the pipeline sections which illustrate the PUF insulation as installed on the pipeline.

Fig. 3 Insulated pipe during installation

D. Design Basis And Solution Parameters

The crude oil to be transported in the pipeline has a high wax content and cannot be transported through conventional pipelines. The viscosity of the oil plays an important role in the hydraulics of the system. Other factors such as wax appearance temperature (WAT) and pour point also dictate the design. The Rajasthan crude shows the following parameters:

- Wax Content: 14-38% by weight
- WAT: 50-65°C
- Wax Dissolution Temperature: >80°C

The critical flow assurance related issue for the pipeline is the potential for crude oil gelation at a pour point 32-42°C. In order to manage wax deposition as well as pour point issues, the heating system must maintain the fluid temperature above the WAT with ground temperatures during winter as low as 22°C.

Creative technology, engineering and construction solutions were implemented to deal with numerous on-the-ground challenges and obstructions. The social and environmental issues are significant on a cross-country pipeline in a newly industrialized country such as India. The project execution plan was based on the concept of least disturbance to the environment, human habitations, forests, and aquatic bodies, avoiding wildlife sanctuaries, archeological monuments and places of worship. Thus the optimum solution for the pipeline could not be the shortest route, but a route that would not compromise the environment, causes minimum disruption to the livelihood of local people and gains the acceptance of all the communities along the route.

In India the availability of stable and reliable electric power is a problem, especially so in the remote regions traversed by the MDPL. The utility power grid was not considered to have sufficient reliability for use as the primary power source. However, grid power was utilized as a backup.

E. Integrated Heat Management System

The emergence of long distance heated crude export pipelines has increased the need to evaluate and adopt new and emerging technologies and integrate applicable technologies into heat management solutions. This method combines thermal modeling techniques, optimized heat application methodologies, various types of pipeline monitoring such as fiber optic based sensing for temperature sensing, intrusion protection, leak detection, sophisticated control and monitoring systems and advanced mathematical modeling for crude oil heat up and cool down scenarios under steady state and transient conditions.

The MDPL project used Finite Element Analysis (FEA) to model thermal profile scenarios under steady state conditions. These FEA evaluations include prediction for cool down time for crude wax formation, time taken to re-heat crude to 75°C and Computational Fluid Dynamics (CFD) analysis to evaluate thermal profiles under various flow conditions. Transient analysis was performed to analyze the melting process of congealed crude and wax dispersal to resume flow in the pipeline.

Thermal insulation systems were analyzed to establish the most suitable thermal insulation material and application methodologies to insulate the pipeline and meet the challenges facing an underground installation. The fact that the pipeline is exposed to several water crossings and a high water table, among other moisture ingression possibilities, made a 100% water resistant moisture outer jacket a prime requirement.

A pre-insulated / pre-fabricated thermal insulation system with high temperature foam and extruded High Density Polyethylene (HDPE) outer jacketing with suitable thickness to provide mechanical protection and prevent water ingress was selected as the thermal insulation envelope over the pipeline. A purpose built pipe insulating facility was established at an Indian pipe mill applying PUF insulation by spray method to speed the manufacturing process and give a high quality homogeneous product.

The segments that cross through seasonally flooded terrain and water body crossings were covered with additional concrete coating for stability and increased mechanical strength as shown in Figure 4.

Fig. 4 Concrete coated insulated pipe

F. Electrical Design Details

MDPL required the design of 50 heating SEHMS circuits ranging in length from 1 km to 10.3km, most being in the range of 8 to 9 km. Table I below defines the design parameters.

TABLE I: DESIGN PARAMETERS

Line No.:	MDPL 24” Crude Oil Pipeline
Pipe Material:	Carbon Steel
Pipe Size:	24”
Pipe Length:	8210 m
Minimum Ambient Temp.:	22°C
Maximum Ambient Temp.:	37°C
Maintain Temperature:	65°C
Operating Temperature:	75°C
Maximum Exposure Temp.:	125°C
Insulation Type:	Polyurethane Foam (PUF)
Insulation K-factors:	0.027 W/m.K
Insulation Thickness:	90 mm
Above/Below Ground:	Below Ground
Heat Up:	From 22°C to 65°C (~15 days)
Supply Voltage:	415V, 3-phase
Frequency:	50 Hz
Area Classification:	Non-Hazardous

Two types of SEHMS circuit configurations were used in this project. The majority of the circuits used Scott-T transformers to power two SEHMS heaters from the middle, each going opposite directions. Scott-T transformers convert 3-phase power to 2-phase power; if the 2-phase load is balanced (in this case, if the two SEHMS heaters powered from the middle are close in length), the primary 3-phase supply will be nearly balanced. The single-phase SEHMS circuits used a Load Balancing Unit (LBU) in order to provide a nearly balanced 3-phase power supply. In an LBU a power factor correction capacitor bank is first added to give the SEHMS load a unity power factor; another capacitor bank and a reactor are then added and sized such that the line currents are approximately equal. Taps are used for both the capacitors and reactors to allow field adjustment of the capacitance and inductance values. Figure 5 is a typical single-line diagram for a SEHMS circuit using an LBU.

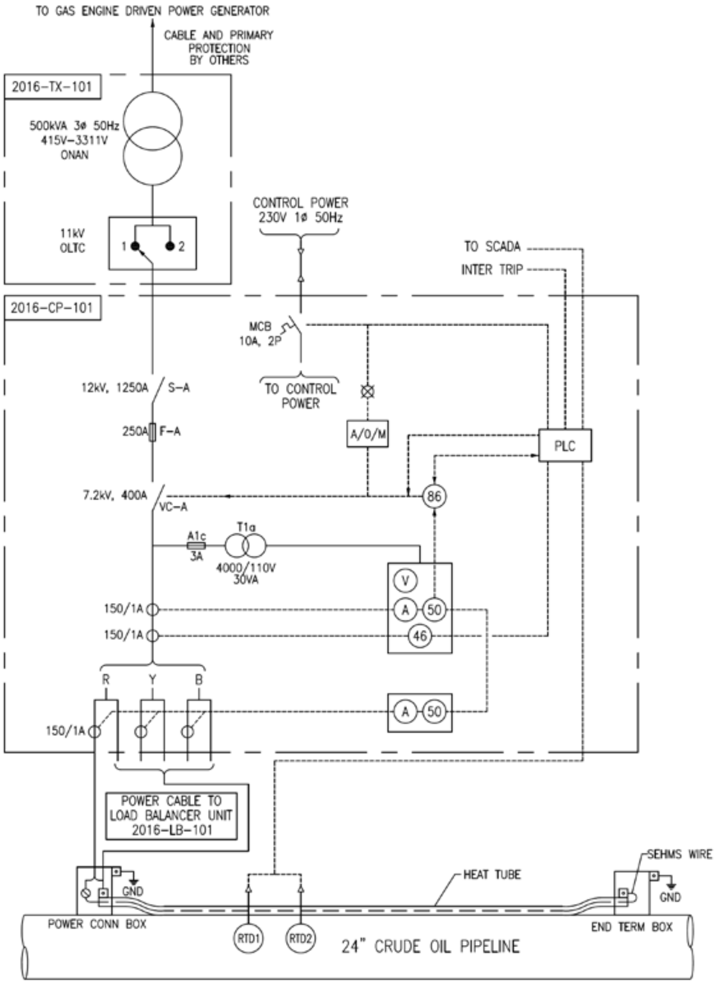

Fig. 5 SEHMS system single-line diagram

Table II below illustrates typical design information for an LBU type circuit.

TABLE II: ELECTRICAL DESIGN INFORMATION

Heat Loss (no safety factor):	28.9 W/m
Conductor:	21mm2, 150°C, 5kV
Total Circuit Length:	8210 m
Heat Tube:	1" Seamless Carbon Steel
Number of Heat Tubes:	1
Attachment Method:	Welded
Output at Maintain Temp.:	40.0 W/m
Output at Start Up Temp.:	43.5 W/m
Operating Load:	357 kVA
Panel Type:	IP41, Indoor
Transformer Size:	500 kVA, 3-phase, 50 Hz
Primary / Sec. Voltage:	415V / 3303V
Transformer Type:	Oil-filled / Outdoors
Load Balancer Size:	500 kVA
SEHMS Operating Voltage:	3.3 kV
SEHMS Steady State Current:	108A
SEHMS Start Up Current:	117A

The primary power requirements were met by gas fired generators located at each of the 36 pipeline stations spread approximately every 20km along the pipeline route. These gas power stations were fed by fuel gas sourced from the same fields as the crude and transported by a parallel 8" gas pipeline. Table III below presents data for a typical generator.

TABLE III: TYPICAL GENERATOR TECHNICAL DATA

Type Rating:	910 kVA
Driving Power:	493 kW
Ratings at p.f. = 1.0	477 kW
Ratings at p.f. = 0.8	472 kW
Rated Output at p.f. = 0.8	590 kVA
Rated Current at p.f. = 0.8	820 A
Frequency:	50 Hz
Voltage:	415 V
Speed:	1,500 rpm
Power Factor Lagging:	0.8 – 1.0
Efficiency at p.f. = 1.0	96.7%
Efficiency at p.f. = 0.8	95.7%
Moment of Inertia:	19.50 kg.m^2
Protection Class:	IP23
Insulation Class:	H
Total Harmonic Distortion:	1.5%

G. On site Testing – Validation Of Technology

Given that skin effect technology was applied to the MDPL project with a number of innovations it was deemed prudent to validate these by use of a large scale in situ test during the construction period. These tests were conducted to verify the performance of the heating system as designed, and to quantify the heat losses and thermal behavior during the heat up of empty pipe, including the time taken to bring the empty pipe from the soil temperature to the required design temperature. The thermal behavior of the pipeline was assessed for six specific design cases.

Test finding and conclusions:

- The skin effect heating system performed as designed, meeting the heating duty requirement
- The skin effect heating system was able to heat a 24" line from ambient soil temperature to 75°C
- The system was capable of heating an empty pipe to 65°C in approximately 2 days
- The addition of cable pull boxes does not adversely impact the heat delivery
- Maximum spot temperature in all locations remained well below the allowable
- The thermal gradient of the pipe (from heat source to farthest point) was well within acceptable limits
- The performance of insulation was in accordance with the design requirement

The test results gave confidence that the SEHMS would heat the MDPL as required, specifically confirming the suitability for underground service.

H. Safety and Risk Evaluation

The transportation of crude in a heated pipeline not only includes innovations and path breaking technologies, but also touches the social and cultural demography making it imperative to understand the cultural fabric of the society. Community engagement plays an important role in ensuring a safe and secure pipeline. The pipeline passes through land of over 40,000 individual landowners. The challenge was to integrate various technologies to make the pipeline operations technologically safe and strike a balance between community expectations and smooth business operations.

The MDPL pipeline is the longest ever heated by skin effect technology. It was built in compliance with major International codes and practices; some of the technical standards included API 1104 for welding, API 5L for line pipe manufacturing, ASME B 31.3 for piping, ASME B 31.4 for oil pipelines, and ASME B 31.8 for gas pipelines. The pipeline system was also built in compliance with ASME section V, ASME section IX, for welding OISD-STD 141, OISD-STD 117 (Fire Protection), OISD-STD 118 and OISD-STD 108. IEEE standard 844 was used in relation to heat tracing [3]. The project complied with applicable Indian regulations related to health, safety and environment.

The safety measures included corrosion protection, intrusion detection along the entire length of the pipeline using fiber optic cable, and an integrated leak detection system whereby the pipeline is continuously monitored from a control station utilizing a Supervisory Control and Data Acquisition (SCADA) system.

I. Construction

Construction of the 600km phase 1 of MDPL project commenced in June 2008 and the pipeline was commissioned in May of 2010. At peak a workforce of over 5,000 were engaged on the project. In excess of 10 million man hours were expended without any lost time safety incident.

While the main construction contractor was experienced in the field of pipeline construction they, understandably, had never encountered a pipeline with SEHMS.

Fig. 6 SEHMS cable installation

The addition of SEHMS to a traditional carbon steel pipeline dramatically impacts almost every aspect of the construction sequence. For example, a traditional pipeline might have 2 or 3 different types of line pipe, with wall thickness being the differentiating factor. The MDPL project had upwards of 18 types of pipe to accommodate the requirements of the heating and insulation. The logistics of delivering over 50,000 individual pipes, of 18 different types, to specific locations on a 600km route was a monumental logistical task.

Fig. 7 Pipeline installation

The 24" pipe was delivered in 12m long pre-insulated lengths which were laid along the pipeline route. These were then welded together into "strings" typically 1km long, following which the heat tubes would be welded through couplings / pull boxes and pneumatically tested to ensure integrity. The pipe joints were then epoxy coated, an outer electrofusion sleeve installed and PUF foam injected to complete the field joint. Prior to lowering into the trench, the SEHMS conductor was manually pulled into place (Figure 6) to ensure it was not over stressed. The completed string would then be lowered into the trench (Figure 7) which would then be backfilled leaving open only the tie in locations where the strings would be welded together. The surface would then be reinstated to original condition and a hydrostatic test conducted to prove the 24" carrier pipeline integrity.

Quality control during installation was critical, particularly given the remote and difficult terrain of the pipeline route, far removed from workshop conditions. Any defects due to incorrect installation would not become apparent until late in the construction period and after reinstatement of the majority of the pipeline route. Locating and repairing any such defects would be time consuming and difficult. Of the small number of faults which did occur during the first 3 years of operation, the majority were related to SEHMS cable insulation damage during installation.

J. *Unique Challenges*

Implementing a high technology solution on an unprecedented scale presented several unexpected and unforeseen challenges during design, manufacturing and installation of MDPL. One of the key factors that facilitated problem resolution was the very close cooperation between the SEHMS designers, who had the electrical heating system expertise, and the pipeline owner who had specialist pipeline design and construction experts.

A snapshot of some the unique challenges were:

- Negotiating and managing 40,000 individual land owners along the pipeline route, thousands of crossings including railways, roads, rivers, canals, and sensitive environments on the pipeline route
- Setting up a purpose built state of the art PUF/HDPE manufacturing facility for the first time in India
- Design of the pipeline field joints was complex requiring extensive thermal modelling, collaboration between multiple design and supply parties, and extensive testing to get the interface details of PUF and HDPE correct. The joints were protected by electrofusion HDPE sleeves and finally the PUF insulation was injected while simultaneously mixing the base components
- Manufacture of line pipe with continuously welded heat tube. During manufacture the process had to be modified to eliminate cracking of the heat tube
- Eighteen different pipe types created a complex engineering and logistical challenge. Specifying and manufacturing pipe offsite long in advance, then getting the correct pipes to the required locations on site, created a construction “jigsaw puzzle” of mammoth proportions
- Two particularly heavy monsoon seasons (Figure 8) during the construction period caused serious flooding in a number of pipeline sections. Procedures had to be developed to rectify water and mud infiltration of heat tubes

Fig. 8 Monsoon flooding

- Theft / vandalism issues: Securing 600km across open country was a near impossible task. The heavy copper heating cable once installed was an attractive proposition for thieves. Up to 100km of cable had to be manufactured at short notice and air freighted to replace stolen or damaged material (Figure 9). Innovative repair methods were developed and tested to allow repair of damaged heat tubes sections while leaving the carrier pipe untouched
- Quality control in a difficult construction environment with a high percentage of unskilled labor

Fig. 9 Malicious damage and cable theft

K. *MDPL Phase 2*

During execution of the MDPL project a second phase was conceived and developed. This comprised of an extension to the MDPL 70km beyond the existing refineries to a new 2.5 million barrel storage and export terminal to be constructed close to the Arabian Sea coast. From the terminal a 24 inch pipeline would cross 8km of land to the coast and then a further 6km subsea to a loading buoy located in 30m water depth, the pipeline then returning in a loop to the oil terminal. This phase 2 expansion would take the MDPL system to a length in excess of 700km and strategically would give the pipeline owners access to 80% of India’s refining capacity by sea.

The subsea portion of twin 6km pipelines at a depth of up to 30m presented a new range of technical issues. Given the distance of 14km from the terminal to the loading buoy voltage limitations meant that one heat tube would no longer be sufficient to deliver the required power output of approximately 40 W per m. For this reason a second heat tube was necessary. A third heat tube was added to give the heating system 50% redundancy, recognizing the impossibility of repair should a circuit malfunction on the sea bed. This 3-tube design made the fabrication and installation ever more complex.

The insulation used for the marine section had to be redesigned to account for buoyancy issues, the additional mechanical strength to withstand installation stresses and the water pressure on the sea bed. The pipeline joints were redesigned to make them suitable for marine service. The insulating foam used for pipe joints was a specialized marine application material with excellent strength and bonding properties in addition to being impervious to water plus having suitable insulating performance.

On top of the insulation and HDPE jacket the marine pipeline required a concrete weight coating to give buoyancy stability. The bond between the HDPE and concrete was crucial to ensure that the concrete did not shear away from the pipeline under the stresses of installation. New SEHMS cable pull boxes were designed to be stronger and specifically tested to pressures greater than the maximum head of water.

The loading buoy floats on the sea surface above the pipelines on the sea floor, rising and falling with the tides and the waves. A special arrangement of piping and a pipeline end manifold (PLEM) with flexible pipes connect the pipelines to the loading buoy. This interface arrangement also had a requirement for insulation and heating which could not be covered by the skin effect circuit from the terminal. A standalone self-regulating tracing system was designed for this portion, fabricated on board the barge and capable of being powered by a diver installed cable routed from a generator on a service vessel.

It was decided that the marine portion of the pipelines would be assembled in a yard at the landfall point on the coast. All 12km were fabricated in 500m "strings", fitted with buoyancy tanks and then floated out to sea, winched into place by a pipeline installation barge located offshore. (See figure 10). In a carefully coordinated procedure the buoyancy tanks were removed to sink the pipeline into a trench dredged into the seabed. This was then backfilled to protect the pipelines from wave action or shipping interaction.

The marine section of the MDPL phase 2 project has been successfully installed and initial testing on the SEHMS systems indicates the circuits are drawing power as anticipated. The entire system including export terminal is due to be commissioned in 2014.

Fig. 10 Marine pipeline float out

L. Lessons Learnt and Future Considerations

The experience gained executing the MDPL project has resulted in a better understanding of the risks and rewards associated with implementing an underground heated cross-country pipeline. SEHMS is a very effective method of providing thermal energy to the pipeline.

The circuit lengths of the electric trace heating system are a major factor in selecting the ideal technology. Due to the requirement of a large supply of electric power along the pipeline route, taking electric power from utility grids may not be a viable option and finding other sources of electric power could be a major challenge. On site generation of electricity using gas engine generators, diesel power generators, crude oil fueled generators, dependable solar power systems or other novel approaches to generate electricity should be addressed in the early stages of planning.

The use of the pre-insulated piping with high efficiency thermal insulation materials has been an important part of the MDPL solution parameters. The homogenous thermal profile offered by the pre-insulated piping systems significantly enhances the thermal performance of the pipeline.

The experience gained from concept to commissioning of the MDPL project offers significant insight to future underground cross-country pipelines.

Similar projects may benefit from investigating the potential to increase circuit lengths which in turn will increase the spacing of the heating stations and thereby reduce the number required with resulting cost and constructability benefits. Of course, longer circuits translate to higher voltages and associated challenges. Other future considerations include the potential to simplify the installation process by increasing the spacing of cable pull-boxes; however, caution is required to minimize the risk of cable damage during installation.

While skin effect heat management systems are an ideal choice for delivering heat to the pipeline, a combination of other applicable technologies could be bundled to enhance the safety and reliability of the underground pipeline. Technologies available today that may be applicable for these types of pipeline transport include fiber optic based systems, such as Distributed Temperature Sensing (DTS) systems, Distributed Acoustic Sensing technology (DAS) to detect digging and physical intrusion, Distributed Strain Sensing (DSS) systems, and a new generation of technologies to detect and prevent oil spills due to their ability to detect, locate and classify vibration caused by physical activities while simultaneously monitoring for early stage leaks along the entire length of the pipeline in real time. Combining many of these technologies can offer superior real time capabilities to the pipeline in temperature monitoring, leak detection, intrusion detection and thermal insulation failure conditions resulting in more dependable, secure and safe pipeline operations.

III. CONCLUSIONS

The MDPL project illustrates what can be achieved when project stakeholders are determined to overcome stiff challenges and break new ground in terms of application of technology and innovation. The potential rewards in terms of energy security for the nation of India were obvious. However, this had to be balanced with risks associated with failure to deliver a safe and reliable crude export pipeline.

The MDPL project can be used as a template for future development of waxy oil fields. Given the increasing focus on non-conventional oil, MDPL is unlikely to remain a unique project. It will be interesting to see how long MDPL holds the title of the world's longest heated pipeline.

Some of the high level conclusions are summarized below:

- Skin effect technology coupled with pre-insulated piping has been proven to be an effective heating technology for onshore long distance buried pipelines in remote locations
- A similar approach, with appropriate adaptation, can be applied to heated subsea pipelines
- A substantial factor in the success in the MDPL project was the close integration between the project owners, the SEHMS designer and the pipeline engineering / Engineering, Procurement and Construction (EPC) contractor
- The installation challenges associated with such a heated pipeline as opposed to a traditional pipeline are significant and translate into cost and schedule impacts. This must be clearly understood at an early stage of project planning
- Stringent quality control during installation is critical to avoid both the expense and delay at the time of commissioning and failures during the operational phase
- Detailed and accurate as built records are essential to support maintenance during the operational phase
- Security factors can be a challenge given the nature of cross-country pipeline routing in remote regions
- In the initial 3 years of operations, the MDPL pipeline SEHMS has proved to be a rugged and reliable system. Overall pipeline availability has been measured at 99% over this period

IV. ACKNOWLEDGEMENTS

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VI. VITA

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