1995 - The Year of the Pig: hydrotesting and precommissioning the Yacheng pipeline

by Phil Walker

Nowsco Pipeline and Industrial Services, Leeds, UK

The Pipeline Pigging Conference

Hilton Hotel
Jakarta, Indonesia

May 27-30, 1996

Organized by
Pipe Line & Gas Industry
and
Pipes & Pipelines International
with the support of the
Australian Pipeline Industry Association

1995 - THE YEAR OF THE PIG: HYDROTESTING AND PRECOMMISSIONING THE YACHENG PIPELINE

INTRODUCTION

In 1995, the Chinese Year of the Pig, Nowsco completed the hydrotesting and precommissioning of the world's longest single-section pipeline without internal coating - in the South China Sea.

In October, 1994, Nowsco UK was awarded contracts to perform the flooding, cleaning, gauging, dewatering, vacuum drying, and nitrogen filling of the Yacheng pipelines. The Yacheng field is situated in block 13/1 in the South China sea and the pipelines comprise a 28-in gas pipeline, 778km long, to landfall on mainland Hong Kong, and a 14-in gas and condensate pipeline 92km long terminating on Hainan Island, People's Republic of China (see Fig.1).

This paper describes the technical innovations required, the logistical achievements made, and the operational experiences gained during our completion of the Yacheng 28-in pipeline hydrotesting, precommissioning, and associated works.

PROJECT OVERVIEW

Nowsco's work-scope on the Yacheng project included the following:

1. Flooding, cleaning, and gauging of pipelines from onshore to subsea laydown head (pig train one).
2. Reflooding, gauging, and removal of tie-in bladders from pipelines (pig train two).
3. Hydrotest of pipelines.
4. Dewatering of pipelines with dry air (pig train three).
5. Vacuum drying of pipelines to -20°C dew point.
6. Nitrogen filling of pipelines.
7. Nitrogen leak testing of facilities at Black Point, Hong Kong; Nanshan, Hainan Island; and on the Yacheng platform.
8. Various mechanical works as required by our clients including installation of structural steelwork and lifting equipment on the Yacheng platform.

THE PIG OF THE YEAR

Selection and design of a pig for 778km of uncoated pipeline

Travelling the 778km of 28-in pipeline without internal coating is arguably the most arduous task that a pig has been expected to perform. The uncoated steel internal surface of the pipeline combined with approximately 65,000 welds and 3D (3 x diameter) radius bends at the platform made the Yacheng pipeline a daunting prospect for any pig. Whilst the first run was less onerous in that the minimum bend radius was 5D (the platform had still to be tied-in to the pipeline at that stage), the schedule was such that pigs for the second run had to be ordered before the results of the first run could be assessed. We had to get it right first time.

The fast-track nature of the project allowed no time for pig trials. In any event, it would be very difficult to simulate the effects of a 778-km pipeline. The design of these pigs was based primarily on experience. The final pig design is shown in Fig.2.

The main concerns with the pig design were the wear characteristics of the pig seal discs and support discs on the rough internal surface of the pipe wall. The material needed to be sufficiently durable to last the distance, yet flexible enough to pass through bends and other pipeline fittings.

It was decided that polyurethane support discs alone could not be relied upon to support the pigs over this distance, and some other means of support had to be provided. In order to maximize the support with minimal restriction to the pig movement, we chose to fit wheels to the pigs. These wheels were fitted in two sets of four mounted radially about the pig's body. The wheels were mounted in this manner such that, in any configuration or orientation of tee, they would support the pig centrally and co-axially in the pipeline. The pig could not tip forward or back; (a common failure mode on long-distance, dry-running pigs is for support discs to wear out at the front causing the pig to tip forward and hence lose drive).

The design criteria that we stipulated for the support wheels were:

A. each wheel had be capable of supporting the weight of the entire pig alone.
B. the wheels had to be capable of retracting into the wheel housing sufficiently to allow the pig to traverse a 3D bend without excessive pressure.
C. the wheels had to be sufficiently durable to travel 778km and still rotate and retract into the housing (as the bends were at the end of the run).
D. the wheel housings had to be ventilated to prevent hydraulic lock or debris build-up which could prevent the wheel retracting.
E. the wheels had to be proprietary wheels with a track record of long running in hostile environments.

The wheels chosen were of a type used commonly on tracked vehicles and heavy-duty industrial conveyor belts. A urethane tyre was added to the wearing surface of the wheels.

In order to initiate and maintain a rolling motion in the pigs to encourage even wear, the wheels were mounted at an angle of 2° from the axis of the pig. The wheels were positioned slightly within the pipeline ID such that the wheels only contacted the pipe wall when the support discs were slightly worn.

Two traditional support discs were fitted to either end of the pig to help keep the pigs straight and to guide them through the pipeline bends. These support discs also provide a hard surface to assist cleaning and push debris ahead of the pig.

Four sets of sandwiched sealing discs provided the fluid seal and hence the drive for the pigs. The twin and triple discs of relatively-thin urethane allow a greater deformation of the discs without wrinkling as the discs slide against each other. Multiple sealing discs also offer improved wear characteristics, as only one of the multiple discs is in contact with the pipe wall at any time, thus retaining the full disc diameter for longer.

PIG RESULTS

All the pigs reached their destination without difficulty and on schedule during the flooding and gauging operation, the pigs by-passed less than 1% of water pumped during the first two pig runs, and during dewatering by-passed approximately 1% of the air delivered. These figures are from a comparison of metered flow with anticipated and actual arrival times.

The success of the subsequent vacuum-drying operation demonstrated that the water residual after dewatering was less than that normally assumed following a pipeline dewatering operation. This is a remarkable result considering the length of the pipeline.

Inspection of the pigs after the 778km showed that the wear to all discs was even, and the sealing discs were still capable of forming a seal in the pipeline. The wheels had clearly performed their support duty, though there was minor damage to some of the urethane tyres.

FLOODING, CLEANING, BLADDER REMOVAL, AND HYDROTESTING

From award of contract to pumping 11m³/min treated water into the Yacheng pipeline from Hong Kong took 60 days. This included engineering preparation and shipping of 240 tonnes of equipment from Nowsco bases in the UK, USA, Canada, and the Far East, and 180 tonnes of water-treatment chemicals. 22 people were mobilized from Nowsco bases around the world for this first operation.

A project management and logistics centre was established in the People's Republic of China in close proximity to our clients.

The flooding of the Yacheng pipeline required the pumping of 280,000 tonnes of chemically-treated water in 18 days - 24 hours a day. Water was pumped out of Hong Kong's 'Fragrant Harbour' (the English translation of 'Hong Kong') using a containerized pumping skid of five electric submersible pumps lowered into the harbour by derrick barge. The installation had to be capable of weathering possible typhoon conditions during the six months it was to be installed in the harbour. Each of these pumps was powered independently from five 250-kVA diesel generators via sealed, combined power and control cables. Each of these pumps was capable of delivering up to 3.2m³/min. These pumps discharged into 50-μ back-flush filters which automatically flushed debris back through a separate manifold into the sea. From the filters the flow of water was routed into a series of break tanks. Low-pressure, high-volume transfer pumps delivered the water from the break tanks to the two high-volume, high-pressure, centrifugal-flooding pumps at the suction head pressure they required. The main flooding pumps were 1800 BHP units and capable of delivering up to 11m³/min of water each at up to 50bar discharge pressure.

A slug of lubricating water and rinsable gel was injected in front of the train to help reduce the abrasion of the dry pipeline. As the pipeline is predominantly downhill from Black Point, a viscous, crosslinked, gel was injected in front to stop the water and lubricating gel running away from the pig train.

Further lubricating gel was included in this train which was mixed on site and injected between the brush pigs. The initial flooding pig train details are shown in Fig.3. The rinsable pipeline gel is a water-based gel which will hold pipeline debris in suspension even when stationary. As the name suggests, the gel is rinsable and is easily removed from the pipe wall by light flushing. This was particularly important, as a residue could have hindered the subsequent drying operation. The gel is also environmentally friendly and fully biodegradable.

Water-treatment chemicals were injected into the flow upstream of the main flooding pumps. The chemicals injected were oxygen scavenger and biocide. A total of 80 tonnes of water-treatment chemicals were injected into the pipeline flooding water during the first run.

The pigs were all preloaded into an adapted subsea laydown head and launched via a manifold whereby the flow of gel and water could be diverted behind each pig in sequence.

The pigs were received into subsea laydown head which was subsequently recovered to the deck of a dive-support vessel and the pigs removed.

Nowsco instrumented data gathering units known as FREDAs (free-ranging electronic data-acquisition units) were fitted to two pigs in the initial flooding run. The FREDA is an instrumented canister which is fitted to the pig and is equipped with pressure and temperature transmitters, an odometer wheel, and an orthogonal triad of accelerometers. Together, these instruments provide a picture of the dynamics of the pig and pipeline medium. The FREDA output provides the following data:

- elapsed time
- distance travelled
- drive pressure
- temperature of drive medium
- acceleration in three (x, y, z) axes

An example of output from a FREDA is shown in Fig.6. These data can subsequently be interpreted to provide the following:

In the event of gauge plate damage, the accelerometer data, combined with drive pressure data and odometer data can be used to help locate the internal diameter anomalies indicated by the damaged plate. With a standard gauge pig, there is no way of ascertaining where any gauge plate damage may have occurred.

The decay in the temperature of the flood water as it traverses the line can be analysed to help predict the pipeline hydrotest stabilization period as the water in the pipeline reaches equilibrium with the ambient subsea temperature.

The temperature profile of the pipeline can be input into the vacuum-drying model to tune the drying prediction.

Following initial flooding, the pipeline construction contractor performed the tie-ins to the Yacheng platform and installed two tees for a future mid-line compression platform. To effect these tie-ins, the construction contractor installed eight weld bladders at both the KP500 point and at the base of the platform riser. The purpose of the second pig run was to remove these bladders by displacing them through to the platform and to gauge the complete pipeline from onshore termination flange to offshore pig trap. The bladders from the mid-line tee insertion were pushed 500km to the Yacheng platform by this, second, pig train.

The second pig train was made up as shown in Fig.4, and was run using treated sea water in the same manner as pig train 1. Treated seawater from the pipeline was discharged overboard at Yacheng through a drill-cuttings' caisson via a 12-in manifold installed from the pig launcher.

The water-treatment chemicals were chosen to have minimal environmental impact and approval for their discharge gained from the Chinese authorities before commencement of flooding operations. For this reflooding and gauging run, the chemicals injected were biocide, oxygen scavenger, corrosion inhibitor, and rhodamine dye.

During bladder removal and gauging operations the hydrotesting equipment was installed. 3000BHP of pumping capacity was installed, capable of delivering 7.5m^3/min.at pressures of up to 300bar. The specified pressurization rate for this pipeline was 0.3bar/min, which required a flow of treated water of 4.86m^3/min up to the test pressure of 195.7bar. The volume of water required to raise the pressure in the line by one bar was 16.2m^3.

The pressure was then allowed to stabilize with top-up as required. Stabilization took place as the relatively-high temperature of the fill water decayed to reach equilibrium with ambient subsea temperature.

From first reaching test pressure to final acceptance, including stabilization, the hydrotest was held for seven days.

14-IN PIPELINE OPERATIONS

Similar operations were carried out on the 14-in pipeline from Nanshan, Hainan Island. Although the engineering of the 14-in pipeline work was less onerous, the logistics of getting equipment and personnel to site were more problematic than in Hong Kong. Importing equipment directly onto Hainan Island was not a viable option, and all equipment was transported via Hong Kong, through customs into China, and by road and ferry to Hainan Island. Nowsco's project management office, just over the border from Hong Kong, was a convenient control centre for all these equipment and personnel movements.

Cranes, general site plant, and engineering supplies, taken for granted in Hong Kong and elsewhere, are more difficult to source in rural China, so careful planning was required.

DEWATERING

Following hydrostatic testing the water from the pipeline had to be displaced prior to commencement of vacuum drying. The length of the pipeline and consequential friction losses combined with the maximum water depth of 148m meant that a substantial compressed air package had to be installed. A dry-air spread consisting of 14 primary compressors, five booster compressors, and three drier packages, was mobilized from the Nowsco compressed-air fleet from UK, USA, and Singapore, and installed at Black Point, Hong Kong. The spread was capable of delivering 22,000Nm³/hr of air with a dewpoint of -40°C up to a maximum pressure of 60bar.

A train of eight pigs as shown in Fig.5 was launched from the permanent pig receiver at Black Point. Two 200-m³ slugs of fresh water were included at the front of the train to flush residual salt and chemical deposits from the pipe wall. These deposits may have proven detrimental to the drying process.

As fresh water was unavailable at Black Point and delivery by road tanker would have been time-consuming and costly, a delivery barge was chartered. The barge, normally used for delivering drinking water to communities on the outlying islands of Hong Kong, moored alongside at Black Point and delivered the 400 tonnes of water into tanks from where the water was pumped directly into the pipeline between the pigs.

The flow of air into the line behind the dewatering train was monitored using an orifice plate flowmeter at Black Point. Dryness was also monitored using dewpoint hygrometer. The water from the pipeline was discharged overboard and the flow monitored using a magnetic-flux flowmeter. Overboard discharge was through the 12-in manifold tied-in to a drill-cuttings' caisson, as used during the reflooding and bladder-removal operation.

The dewatering operation was completed in 30 days including launch and recovery, which was one day ahead of schedule.

The final three pigs received at Yacheng were very dry and brought no measurable water ahead of them. Following recovery of the train, the residual air was vented from the line at both Black Point through a silenced vent and at the Yacheng platform in preparation for vacuum drying.

VACUUM PUMP SELECTION AND DESIGN

The Yacheng pipeline is the largest pipeline ever to have been vacuum dried. A suitable vacuum pump spread to perform the Yacheng 28-in pipeline drying in a reasonable period of time did not exist. Nowsco had to specify and purchase a suitable vacuum pumping spread. As there were space limitations offshore, the drying had to be performed from the Black Point end of the pipeline only.

For drying the longest pipeline ever to be dried by vacuum drying, the largest vacuum pumping spread had to be assembled. The spread had a nominal pumping capacity of 40,000m³/hr, and required a combined load at start-up of approaching 1MW.

The principle of the vacuum drying process is that the pressure in the pipeline is reduced to the saturated vapour pressure (SVP) of the residual water in the pipeline. When the pressure in the pipeline reaches the SVP, the water 'boils'. The resulting water vapour is then pumped out and discharged through the vacuum pump exhaust. It is therefore essential that the pumps produce their most efficient pumping performance at and below the SVP. As the SVP varies with temperature, in hotter climates vacuum pumps need to do their work at higher pressures than in European climates.

Vacuum pumping in hotter climates had presented problems in the past to equipment designed for European climate, due to the higher pumping pressure required and the fine tolerances inherent in most vacuum pump designs.

Traditionally, vacuum pumps for pipeline-drying applications consist of a backing or roughing pump, which is designed to pump a large mass of gas at higher pressures, and a Roots-type blower or booster which must be started at a lower pressure, typically 35mbarA, which will pump large volumes at these low pressures.

For the Yacheng application, it was important that the higher-pressure performance could be improved upon. This was important, firstly, because of the large pipeline volume where the time taken to pump down to SVP is considerably longer than on most drying applications. Significant time savings could be achieved by reducing the time to pump down to the SVP. Improved performance at higher pressure was also important because of the higher SVPs likely in the high ambient temperatures of the Far East. For these reasons, a frequency-converter control was specified for the booster motor. Fig.7 shows a comparison of vacuum pump performance with and without frequency-converter control.

The frequency-converter control allows the booster pump to be started at much higher pressures, albeit the pump will not be running at full speed. The frequency converter controls the motor on a constant-torque basis, using a current-limiting system. If the load on the pump increases such that the motor current exceeds the set limit, the motor is slowed until the maximum current is maintained.

It can be seen that in large-volume systems there is considerable advantage to be gained in using this frequency-converter control in additional pump performance during pump down to SVP.

Another important design premise for the pumps was that the pumps be capable of operating in high ambient temperatures. Nowsco specified that the pumps be capable of operating in 40°C ambient temperatures. For this reason, the pumps used were high-operating-temperature pumps. The operating temperature of vacuum pumps is critical to their efficient running due to the narrow tolerances inherent in their design. Instead of attempting to combat high ambient temperatures, high-operating-temperature pumps were chosen and the high ambient temperatures used to advantage. In cold-running pumps, there is frequently a problem of water vapour condensing as it is compressed from vacuum to atmospheric pressure within the pump. Water condensing within the pump in this way can cause contamination of the lubricant, and means the pumps need to be shut down frequently for water to be drained off. By operating the pumps in excess of 100°C the water vapour remains as vapour through to the pump exhaust. The pumps used for Yacheng were designed to operate at 120°C.

Because of the length of the line and the associated friction losses, it was also important to purchase pumps that would move large volumes of water vapour at very low pressures. This was especially true as pumps were installed at one end of the line only and in order to reach the required pressure at the far end of the line, the pumps need to be performing well at pressures below 1mbarA.

VACUUM DRYING AND NITROGEN FILLING

Vacuum drying began with the start-up of the 40,000m^3/hr pumping spread installed at the Black Point end of the pipeline. While drying from both ends could have reduced the drying time significantly, no vacuum equipment could be placed offshore due to space limitations. A few days after start-up, the first of several unplanned interruptions occurred. These were caused by other mechanical works and resulted in the line being returned to atmospheric pressure on two occasions.

During the period between award of contract and the start of drying, engineering effort was directed towards analysis and prediction of the drying process in this pipeline. The in-house computer model used by Nowsco since 1989 was rewritten to model the transient pressure response and other factors such as the outgassing of steel surfaces. Two of the more useful results of this effort were that the stabilization time of the pipeline in response to an event (e.g. the stopping of a pump) could be predicted, and that the drying effect of a dry gas purge could be analysed. Hence the model proved useful in predicting the effects of the unplanned interruptions.

During development of the model, it became apparent that the potential friction losses in 778km of pipeline were greater than originally anticipated. For this reason, a compressor and air drier were mobilized to the Yacheng platform and a trickle purge of dry air introduced to the pipeline to assist the drying process. It was predicted, and subsequently proven, that the water-removal rate could be enhanced by running dry air through the pipeline at a predetermined optimum rate whilst vacuum drying.

Dryness was accepted as -20°C on schedule after 60 days' pumping

At the end of drying, a summation of the water extracted showed that the dewatering train had left a quantity of water equivalent to a film thickness of 0.05mm, about half the conventional estimate. This was the best performance that we could have expected from the Yacheng dewatering train, particularly when considering the length of the pipeline and the absence of internal coating.

The second repressurization to atmosphere, which took place before drying was complete but which was necessary due to the valve works, was carried out with nitrogen. This was to ensure that the residual gases in the line were oxygen-free and hence allow product gas start-up without further purging or pigging. Nitrogen storage tankers and diesel fired nitrogen vapourizers were mobilized from the UK, and following issuance of a dangerous-goods licence from the Hong Kong authorities, this nitrogen equipment was installed at Black Point. Using this equipment, a total of 224,000kg of liquid nitrogen was vapourized and injected into the pipeline.

Finally, the line was left under vacuum in readiness for gas start-up. The commissioning operation was reportedly successful and the delivered gas purity and dryness within specification.

NITROGEN LEAK TESTING

As an addition to our contract work scope, our clients requested that Nowsco carry out the leak testing of the facilities at Black Point, Hong Kong; Nanshan, Hainan Island; and on the Yacheng wellhead and production platforms.

In order to satisfy these leak-testing requirements, a dedicated specialist Nowsco crew and spread of equipment was mobilized. The work was administered and controlled by the project management infrastructure that we already had in place in China.

Detailed leak-testing procedures were prepared in accordance with the instructions of the local construction manager at each site. Two Nowsco skid-mounted nitrogen pump units capable of pumping at up to 7,500Nm^3/hr at up to 690bar were mobilized, together with 12 liquid-nitrogen tanks each of 8000-li liquid nitrogen capacity. By working closely and flexibly with our clients, the logistics of personnel, equipment, and liquid nitrogen were arranged to suit the construction programmes at each location. By careful planning and co-ordination of liquid nitrogen, equipment, and personnel movements, the leak-test crew travelling and stand-by times were kept to a minimum. The tanks were kept in constant rotation and were either in use on site, in transit, or being refilled at the supply base. The supply base is 48hrs by truck and ferry from Nanshan, and 36 hours sailing time from the Yacheng platform.

A total of approximately 260,000kg of liquid nitrogen was transported to the three locations, pumped, and vapourized, to effect this testing work.

ADDITIONAL MECHANICAL WORKS

During the course of the project, our clients required Nowsco to perform some additional mechanical works. These primarily comprised the removal and replacement of five pipeline ball valves.

In order to handle these valves, each weighing in excess of 15 tonnes, we were required to install additional structural steelwork and lifting equipment to allow valve removal and transfer to location accessible by crane.

These mechanical works were mainly subcontracted to local companies but supervised and monitored by Nowsco's project management team on site and in the local project office.

On reinstatement of the valves, all the disturbed flanges were leak tested as part of our leak-testing scope. This testing included testing the downstream flange on the platform ESD valve for which a flange testing stopper was purpose built.

CONCLUSIONS

The successful hydrotesting and precommissioning of the Yacheng pipelines can be attributed to a number of factors.

- Rapid response and careful logistical support from Nowsco bases around the world.
- World-wide resources: specialist equipment and personnel offering a complete range of pipeline and process precommissioning services.
- Flexible project management approach to additional challenges outwith our usual scope of work.
- Application of a combination of experience and innovation to designing the best pig.
- Innovative approach to vacuum pump design for pipeline applications.
- Early establishment of local project office in close proximity to our clients and worksites.

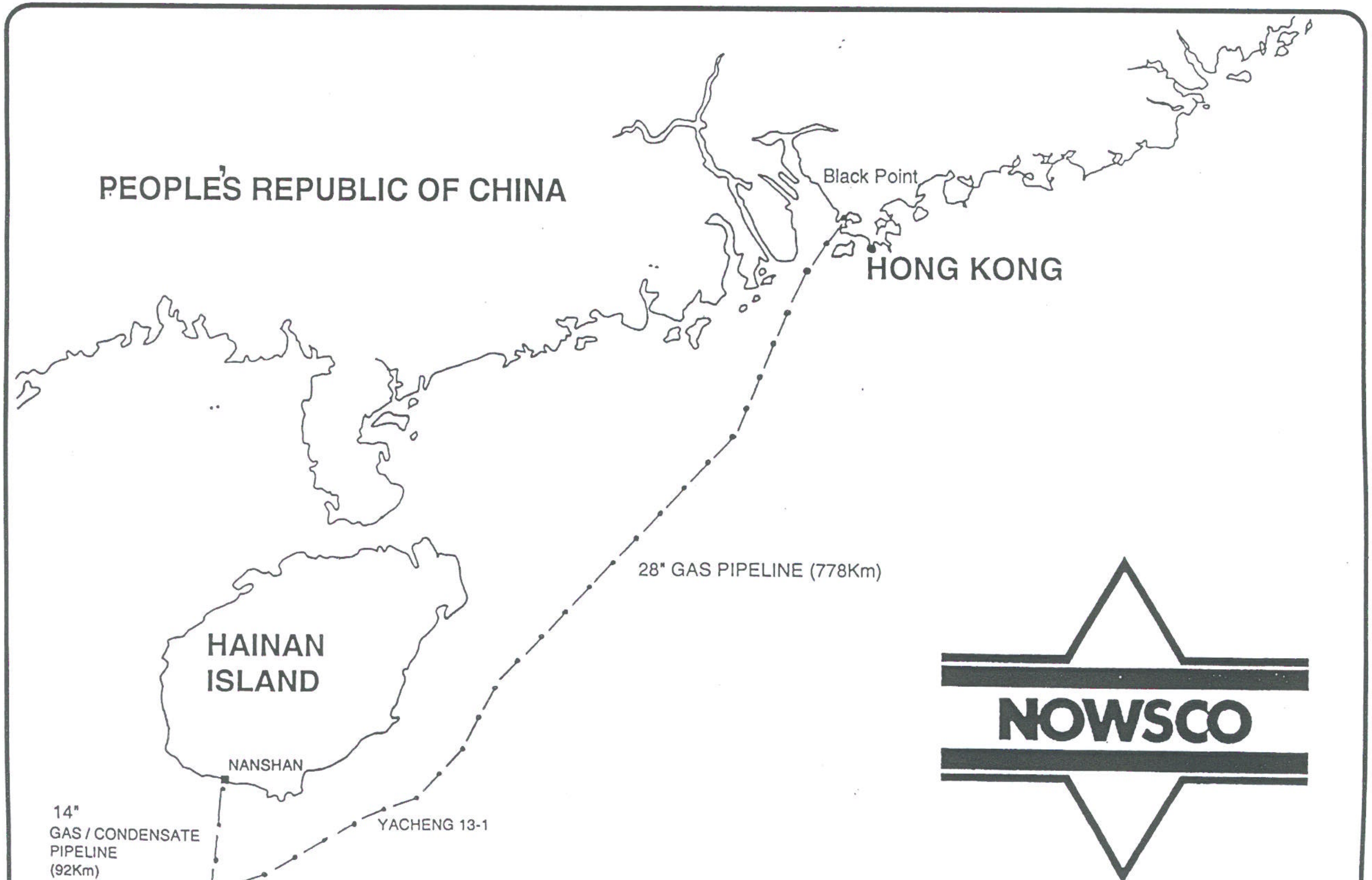


FIGURE 1: YACHENG 13-1 PIPELINES LAYOUT

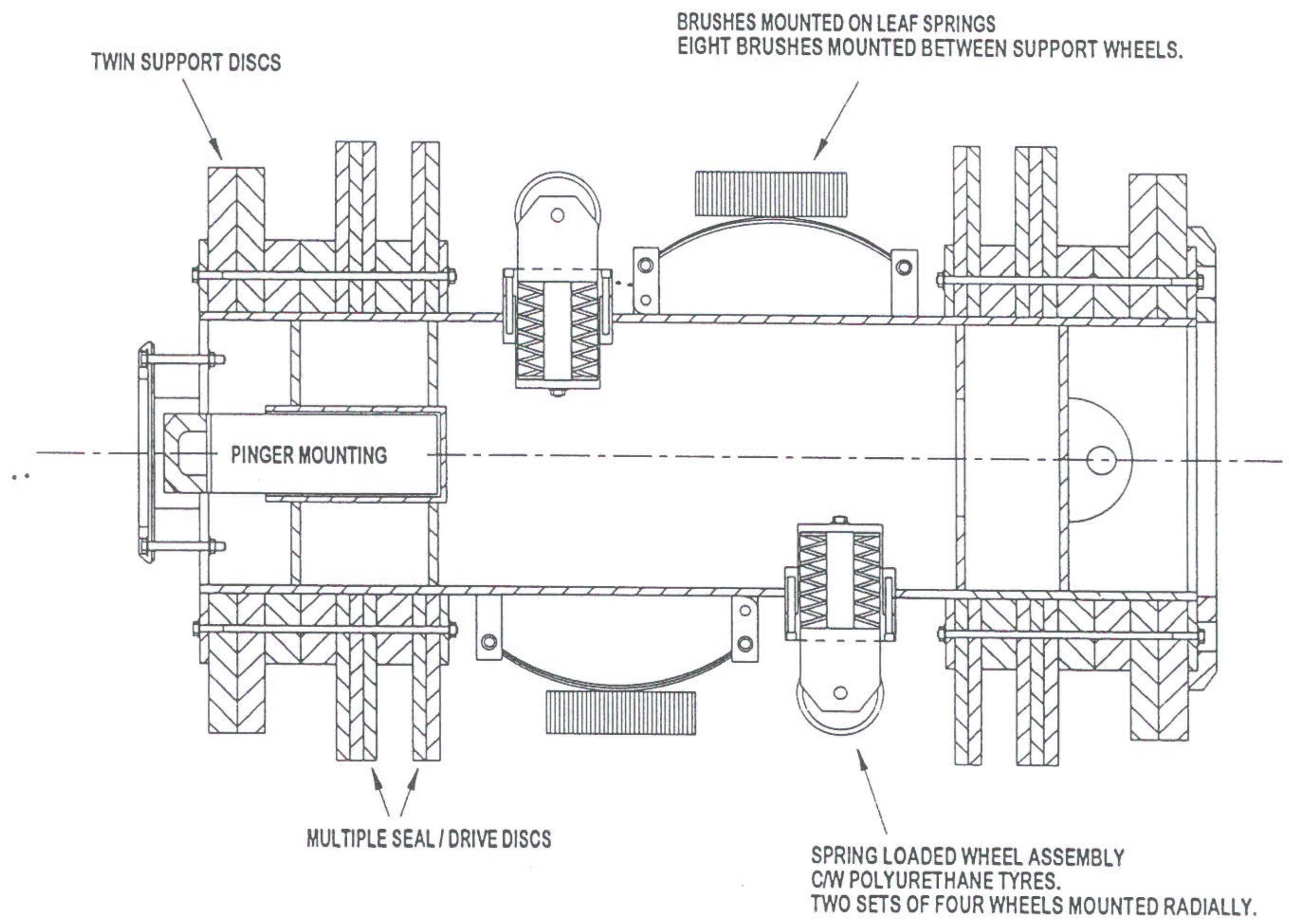
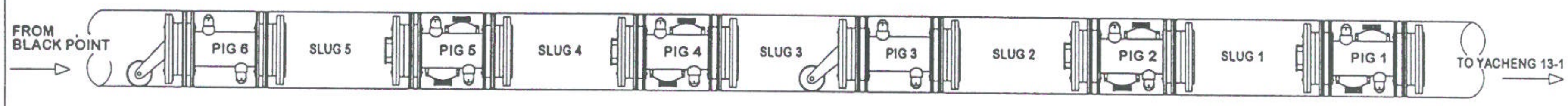


FIGURE 2 : YACHENG 28" PIG DESIGN

NOWSCO



PIG CONFIGURATIONS

PIGS 1, 2, 4, AND 5 : HISEAL BIDIRECTIONAL BRUSH PIGS

PIGS 3 AND 6 : HISEAL BIDIRECTIONAL PIGS WITH GAUGE PLATE AND NOWSCO FREDA* TOOL

* THE FREDA TOOL (FREE RANGING ELECTRONIC DATA LOGGING APPARATUS) IS A SEMI - INTELLIGENT TOOL WHICH LOGS PRESSURE, TEMPERATURE, AND ACCELERATION DATA.

PIG TRAIN FLUIDS

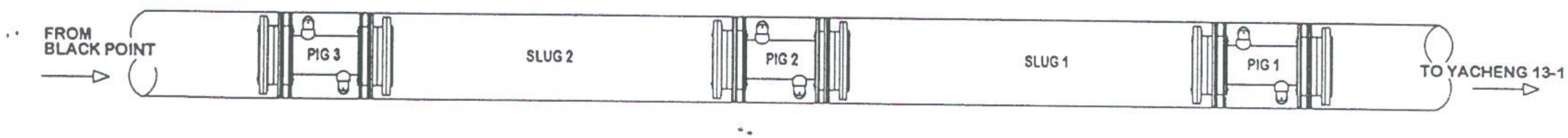
FLUIDS AHEAD OF PIG TRAIN: 400m3 FILTERED TREATED SEAWATER
15m3 CROSS LINKED SEPARATOR GEL
85m3 DEBRIS PICK-UP / LUBRICANT GEL

SLUG 1 : 140m3 DEBRIS PICK-UP GEL
SLUG 2 : 1000m3 FILTERED TREATED SEAWATER
SLUG 3 : 1000m3 FILTERED TREATED SEAWATER
SLUG 4 : 140m3 DEBRIS PICK-UP GEL
SLUG 5 : 1000m3 FILTERED TREATED SEAWATER

FLUIDS BEHIND PIG TRAIN: 280,000m3 TREATED FILTERED SEAWATER

FIGURE 3 : PIG TRAIN 1 - FLOODING, CLEANING AND GAUGING

NOWSCO



PIG CONFIGURATIONS

PIG 1 : HISEAL BIDIRECTIONAL PIG

PIGS 2 AND 3 : HISEAL BIDIRECTIONAL PIGS WITH GAUGE PLATES

PIG TRAIN FLUIDS

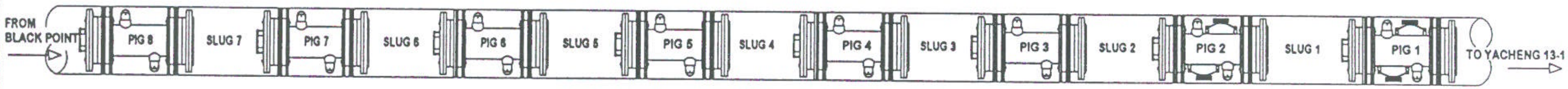
FLUIDS AHEAD OF PIG TRAIN: 15m3 DEBRIS PICK-UP / LUBRICANT GEL

SLUG 2 : 100m3 FILTERED TREATED SEAWATER
SLUG 2 : 100m3 FILTERED TREATED SEAWATER

FLUIDS BEHIND PIG TRAIN: 280,000m3 FILTERED TREATED SEAWATER

FIGURE 4 : PIG TRAIN 2 - BLADDER REMOVAL AND GAUGING

NOWSCO



<u>PIG CONFIGURATIONS</u>

PIGS 1 AND 2 : HISEAL BIDIRECTIONAL BRUSH PIGS

PIGS 3, 4, 5, 6, 7 AND 8 : HISEAL BIDIRECTIONAL PIGS

<u>PIG TRAIN FLUIDS</u>

SLUG 1 : 200m3 FRESH WATER

SLUG 2 : 200m3 FRESH WATER

SLUGS 3, 4, 5, 6 AND 7 : 500m DRY* COMPRESSED AIR AT PROPELLING PRESSURE

FLUIDS BEHIND PIG TRAIN: 280,000m3 DRY* COMPRESSED AIR AT PROPELLING PRESSURE

* MINIMUM DRYNESS OF COMPRESSED AIR OF -40C (AS MEASURED AT ATMOSPHERIC PRESSURE)

FIGURE 5 : PIG TRAIN 3 - DEWATERING

NOWSCO

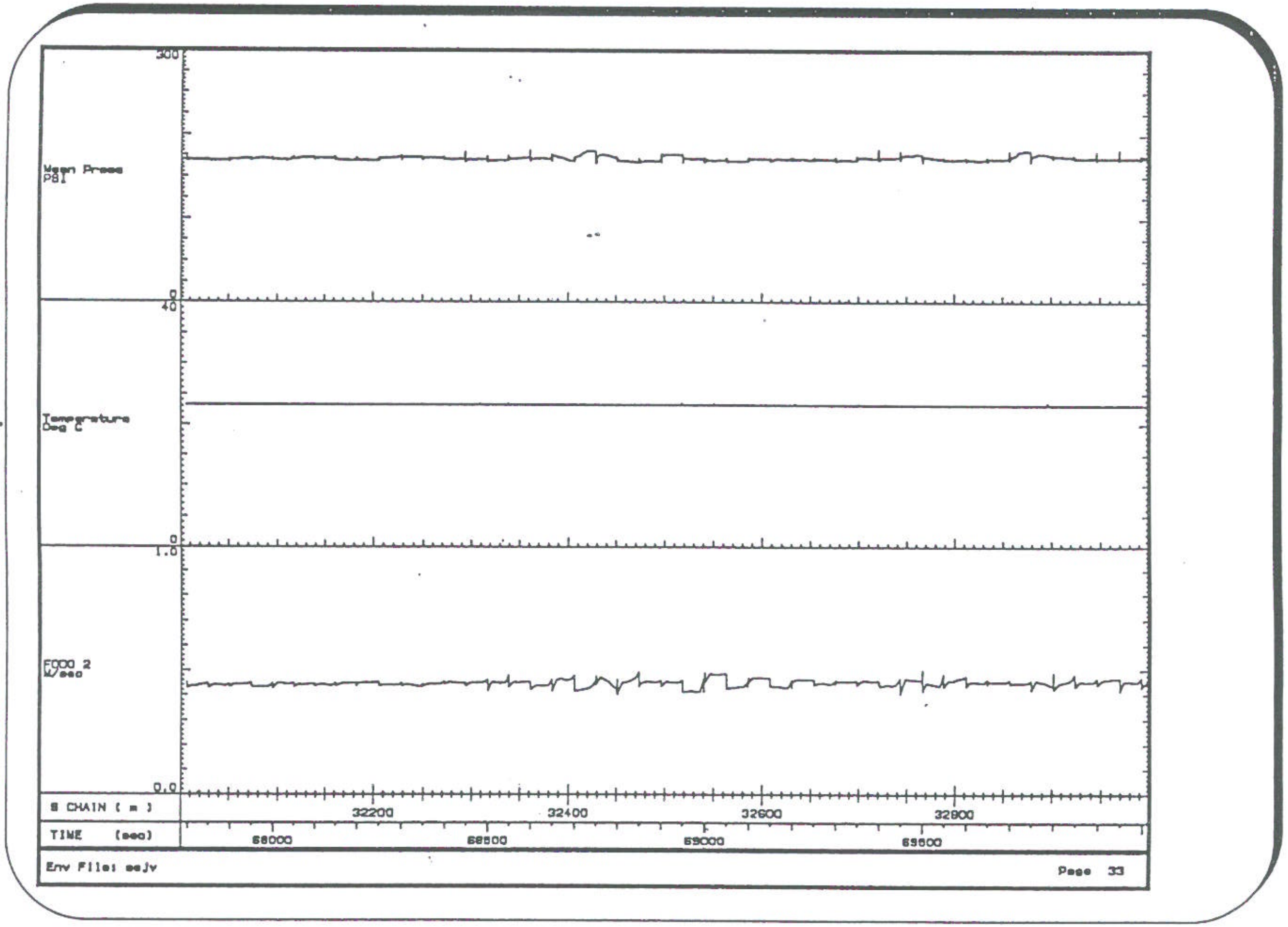


FIGURE 6 : TYPICAL SECTION OF FREDA TOOL DATA SHOWING PRESSURE, TEMPERATURE AND ODOMETER DATA ONLY

NOWSCO

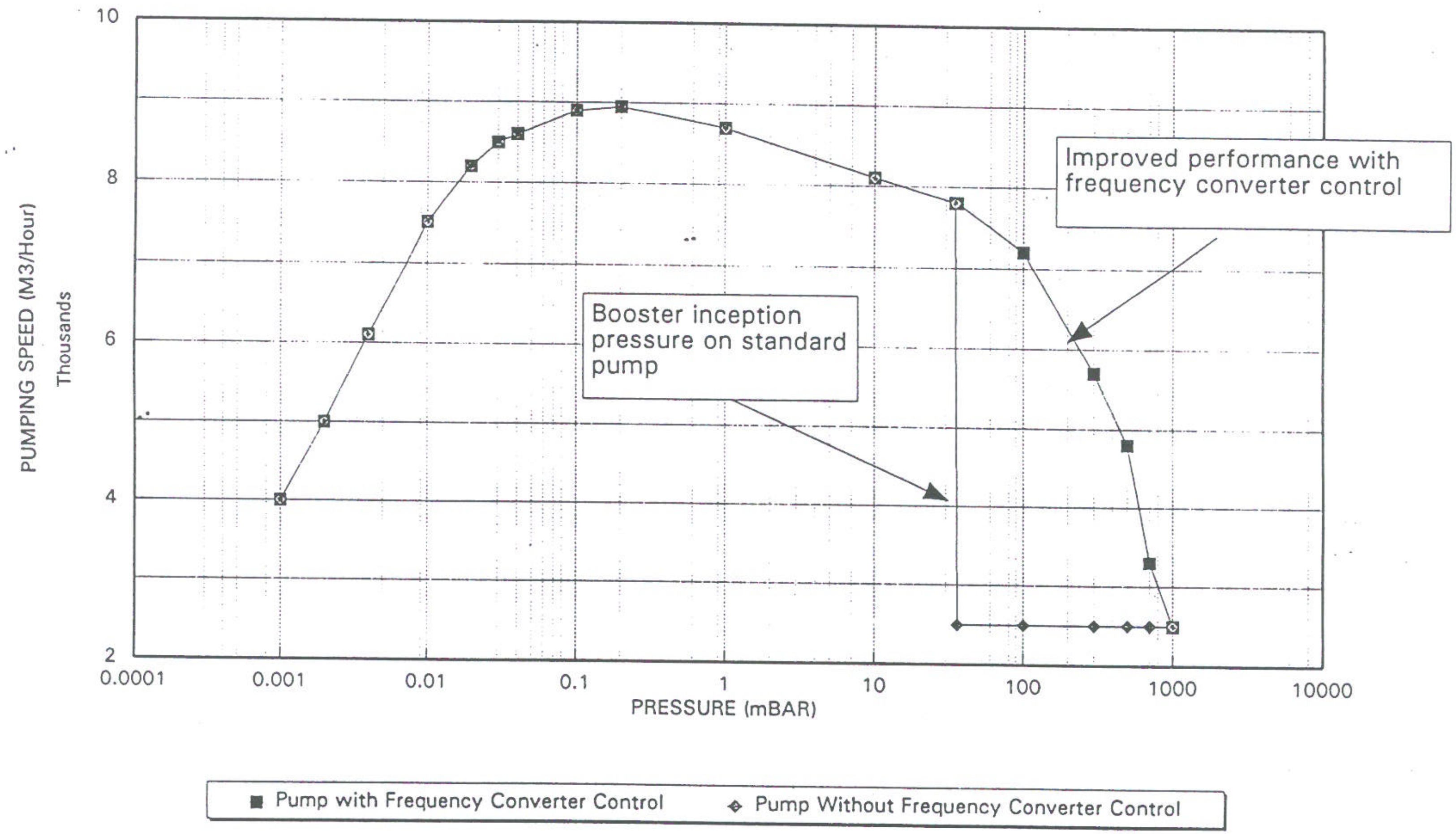


FIGURE 6 : TYPICAL VACUUM PUMP PERFORMANCE CURVE SHOWING THE EFFECT OF FRQUENCY CONVERTER CONTROL

NOWSCO

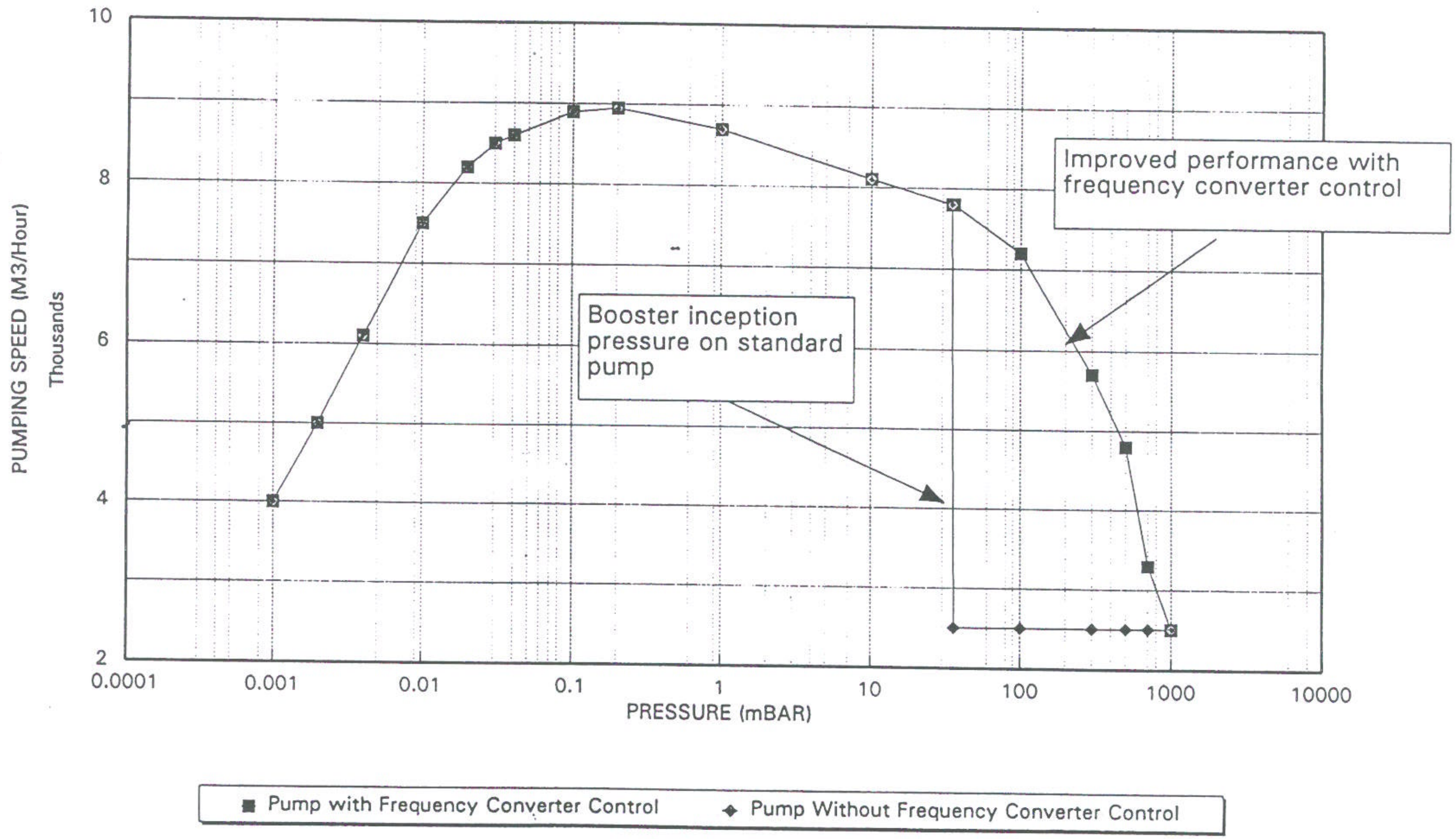


FIGURE 7: TYPICAL VACUUM PUMP PERFORMANCE CURVE SHOWING THE EFFECT OF FRQUENCY CONVERTER CONTROL

NOWSCO