HANDLING OF HIGH WAX NEW ZEALAND CRUDES TUBING TO TANKER

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Petrocorp Exploration

Petrocorp Exploration Ltd discovered New Zealand's first major oil field in 1980. Production is currently 10 000 BOPD.

The crude has a high pour point (32°C) and a high wax level (35%). A major factor in the development of the field was the selection of appropriate technology to overcome various handling and transportation problems from the well production tubing through to export by seaborne tanker. Technical and economic considerations resulted in the selection of mechanical wax scraping in the production tubing, electric heat tracing and insulation of gathering lines, temperature elevation in the production facilities and the use of a chemical pour point depressant for final conditioning of stabilised crude oil. This paper discusses how adoption of the various technologies has resulted in an essentially trouble-free system.

INTRODUCTION

Petrocorp Exploration Ltd discovered New Zealand's first major oil field, McKee, in Taranaki during 1980.

Production of crude oil via the Production Station commenced in October 1984 with 5000 BOPD being produced from four wells. This has been subsequently increased in stages to 12 000 BOPD from 18 wells.

The production strategy is based on a central crude stabilisation and gas treatment facility with individual and manifolded gathering lines from the wellheads. The need to prevent wax deposition in areas of two phase flow and crude solidification after and during stabilisation were recognised as major problems during initial planning.

The following options were eventually adopted:

(a) Mechanical scraping of production tubing using a wireline system to remove deposited wax.
(b) Heat tracing and insulation of all crude oil gathering lines to reduce wax deposition.
(c) Temperature elevation to above the cloud point prior to oil/gas separation and insulation of processing equipment to maintain temperatures and reduce wax deposition.

The marketing strategy was based on bulk storage at the New Plymouth port area with dispatch to markets within New Zealand and overseas by seaborne tanker. Transportation of crude from the production station to port storage was also recognized as a major problem because of the high pour point of the crude.

The use of wax crystal modifiers to reduce the crude pour point was eventually adopted as it was expected to lower the pour point to an acceptable level, minimize the yield point to a level compatible with the pipeline design to assist in the management of pipeline shutdowns, and reduce the apparent viscosity.

These have proven to be acceptable methods with five years successful operation now complete. This paper describes as a case study the reasons why the various technologies were adopted.

CRUDE CHARACTERISTICS

The crude oil has a moderate API gravity (38-39°) and a high pour point of 30°C to 32°C. The crude is a mixed base of paraffins and naphthenes, but it also has a sizable aromatic content. The heavy cuts of the crude are waxy and have high pour points with the overall wax level about 35% wt. The crude is similar in composition to some Indonesian crudes. The crude oil characteristics are summarized in Table 1.

Nature	Paraffinic
Gravity, API	38 to 40
Sulphur, % wt.	Content
Wax content, % wt.	35
ASTM pour point, °C	30 to 32
Shear stress, Pa	0.2 at 43°C
	0.7 at 33°C
	4.8 at 28°C
	19.5 at 13°C

Table 1: Characteristics of McKee crude.

The cloud point has not been established by measurement but has been inferred from pour point depressant performance as between 50°C and 55°C.

The transport properties of the crude can be described in terms of pour point, viscosity at various shear rates and temperatures, and yield point.

The pour point when determined strictly in accordance with ASTM D97-66, is 30°C for both the maximum and minimum values. The yield stress for crude undosed with pour point depressant has never been measured consistently; one measurement made was at 11°C and with the crude cooled statically gave a yield value of 8250 Pa and 12 Pa if cooled under shear. The rheological behaviour is dependent on both shear rate and temperature. Above the pour point the viscosity ranges from 20 cp at 33°C down to 5 cp at 43°C. Below the pour point the viscosity naturally increases substantially to 150 cp at 28°C and 500 cp at 13°C.

WAX DEPOSITION

Initial studies for the field identified the high wax content and its tendency to deposit on cold surfaces and solidify at ambient temperatures as presenting significant production difficulties.

Particular areas of concern likely to require different technological solutions were :

Well production tubing

As the temperature declined to somewhere around the cloud point it could be expected that the wax fraction would deposit on the tubing wall.

Surface gathering lines

The surface two phase flow gathering lines could be expected to operate at temperatures below the cloud point and possibly even below the pour point, with a strong potential for both wax deposition and crude solidification.

Production facilities

With the crude likely to be arriving at the production facilities below the cloud point and maybe below the pour point considerable problems with wax deposition and solidification could be expected as the gas is separated from the crude and the crude stabilised to sales specifications.

TUBING WAX

The deposition of wax on the tubing wall was identified during well testing as a potential production problem. The long term effects were unknown although the initial production tests had indicated that wax would deposit in the tubing and build up with a resultant fall off in production. During production tests a wireline wax cutter was used to remove deposits.

The options considered both for the initial development and subsequently for new and existing wells are discussed.

A major problem with many systems requiring advance design is that the wax deposition profile varies significantly from well to well and cannot be readily predicted. This could result in significant over design or under design as wax deposition occurs at depths varying from 500 m to 800 m, as does the hardness and deposition rates of the wax.

Downhole heat exchanger

The use of a downhole heat exchanger using a circulated hot fluid to reheat the wellstream fluids to prevent wax deposition was rejected initially on the grounds of capital cost and technical complexity. Subsequent experience has shown that selection of depths and heat duties based on the first few wells would have resulted in under design for some of the more recent wells.

Hot oil circulation

The use of hot oil circulation to dissolve wax deposits was rejected because of the high temperatures needed to dissolve the long chain waxes which form the bulk of the deposition, and the significance of lost production during treatment when the wells would need to be shut in.

Internally coated tubing

One of the earlier wells was completed using a polymer lined tubing. This was an experiment to determine if the solidified wax would be removed with the wellstream fluids rather than adhering to the tube wall.

This has not proven effective and has been rejected for current wells.

Downhole chemical injection

Stabilised crude can be modified by a chemical pour point described later in this paper. A theoretical extension of this concept is to introduce the chemical within the well thereby preventing wax problems occurring at all downstream locations. This was rejected for a number of reasons:

(a) The generation of corrosive by products if water is present in all but trace quantities.
(b) The high melting point (45°C) of the pour point depressant which results in high diluent ratios (90%) required to produce a liquid pour point depressant product at ambient conditions.
(c) Difficult to accurately optimise dose rates.
(d) High inventory with annular injection.

Nitrogen filled annulus

The use of a nitrogen blanket in the annulus theoretically shows that a slight reduction in wax deposition will occur. This has been verified in the field where two wells are completed with a nitrogen blanket in the annulus. Wax scraping frequency has been reduced but not eliminated.

The method that was initially adopted and is still in use today is to use a wireline paraffin wax knife to remove the deposited wax. Initially this was done using conventional mobile wireline units with wax cuts every four to six days. In order to free the wireline units for other work and increase production by more frequent wax cuts, a change to permanently installed paraffin wax scraping units was made in 1987.

These units enable wax removal to be undertaken at a frequency determined by the well, rather than wireline unit schedules, and to be done by production operators rather than specialised wireline operators.

Fig. 1 shows the production profiles for a stylised well where a significant benefit from daily wax cutting can be seen.

The one disadvantage of the wireline wax knife is the risk of fishing due to lost tools and cut wire. So far we have lost about 25 days production with fishing.

GATHERING LINE WAX

The initial design for the field allowed for thermostatically controlled electric heat trace and pipeline insulation. Initial operation was based on a target temperature of 50°C with the heat trace providing sufficient heat to raise the wellstream to this temperature from the flowing wellhead temperature of 35 to 40°C. Subsequent experience has refined these operating parameters.

(a) The temperature set point under flowing conditions can be reduced significantly provided regular pigging of the line is undertaken to remove wax deposits. If a well is shut in for a period of time then the temperature can be increased to prevent solidification of the crude.

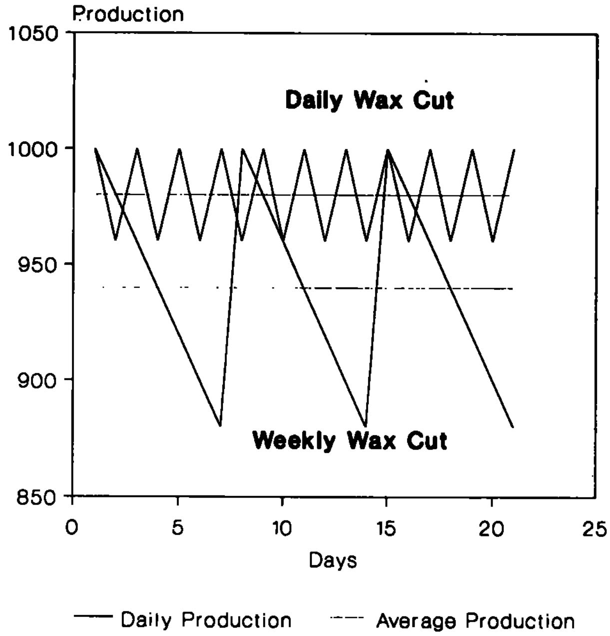

Fig. 1: Effect of tubing wax on production.

(b) Regular pigging with rubber cup pigs is essential, regardless of the crude temperature, to remove wax deposits.

PRODUCTION FACILITIES

Wax deposition in production facilities is prevented by temperature elevation (60°) to above the cloud point in vessels by hot water circulation prior to separation and electric heat tracing and insulation of all lines containing crude oil. Operation of separators above and cloud point may also result in a decreased separator design residence time as there is some evidence to suggest that the formation of wax crystals below the cloud point may inhibit gas/oil and oil/water separation.

An additional benefit of separation at 60°C is that this elevated temperature will aid in breaking oil and water emulsions should they form in the future.

FEASIBILITY STUDIES FOR VARIOUS PIPELINING METHODS

Initial studies for the field clearly identified the high wax content as presenting difficulties in transportation. The investigations covered all possible options for transporting crude from the production station to port storage, a distance of about 40 km. The various options considered, and their eventual reasons for rejection are discussed.

Water/crude systems

Both emulsion and water layer systems were considered and rejected during the conceptual design phase. The limited availability of water at the production station, the prevailing environmental climate which would have required the water to be treated to a very high quality before discharge, and the potential difficulties in obtaining permission to discharge such high quantities of treated water were considered sufficient reasons to reject this option.

Thermal conditioning

The use of thermal conditioning to reduce the apparent viscosity by giving the crude a specific thermal history was rejected on the grounds of capital cost, process complexity, and limited space at the production station for installation of the equipment.

Trucking

While having a relatively low capital cost, the annual operating costs made this uneconomical as a long term option.

Insulated pipeline

The options of a thermally insulated pipeline, together with either a trace heating system, or a preheated crude were all considered. The costs for a system that maintained flowing temperatures were significantly higher than for some other options, without including the additional costs of a system to reheat the crude after a shutdown.

At this stage in the investigations, it became evident from the marketing studies that a number of the potential buyers would insist on a permanent reduction in pour point to less than 15°C. With this limitation now clearly identified, the following three options were studied in more detail, as all three resulted in a permanent reduction in pour point which suited both the market and engineering requirements for transporting crude in an uninsulated line.

Thermal cracking

The use of thermal cracking to break down the long chain molecules was considered in detail and eventually rejected for a combination of reasons that included:

(a) Difficulties in determining the plant size as initial production was 5000 BOPD but expansion up to 12 000 BOPD was possible.

(b) Effluent treatment and disposal in what is an environmentally sensitive area.

(c) The limited hydrotreating capacity at New Zealand's only refinery which was expected at that time to process most of the crude.

Dilution with low pour point condensate

This would have involved diluting the crude with nearby Kapuni or Maui condensate in the ratio of 60:40 crude/condensate to obtain a product with an acceptable pour point. This method was rejected for cost, logistical and marketing reasons:

(a) The storage and pipeline for the condensate would have been substantial as the condensate was available no closer than the pipeline discharge area (40 km).

(b) Prospective buyers indicated that they would prefer to receive New Zealand's crudes and condensates as separate materials.

This method was, however, reserved as a possible backup option.

Use of chemical pour point depressants

Whilst having a relatively high annual operating cost, this method was adopted and it achieved the following objectives:

(a) The crude could be easily transported by pipeline and restarting the line after a shutdown would be relatively easy.

(b) The crude achieved the marketing pour point requirement of 15°C and the use of these (P.P.D.) materials was acceptable to the crude oil buyers.

(c) The system was very flexible in regard to capacity changes.

The decision was then made to use a chemical pour point depressant as preliminary studies had indicated that suitable products for this crude existed and that the costs would be acceptable. Then detailed investigations of suitable products commenced with the detailed pipeline design undertaken simultaneously as suitable laboratory results became available.

The laboratory evaluation of pour point depressants was undertaken by a number of potential suppliers as Petrocorp had neither suitable laboratory facilities nor suitably experienced personnel.

Independent laboratories were used as necessary to verify data provided by suppliers.

PIPELINE DESIGN

In the design of the pipeline the following constraints were specified:

(a) The required capacity was 12 000 BOPD to allow for future (and at the time unknown) expansion from the existing known production of 5000 BOPD to 6000 BOPD.

(b) Intermediate pumping for normal operation was considered undesirable since the length was only 40 km.

(c) The crude temperature at the inlet to the pipeline would be about 60°C.

(d) The ground temperatures ranged from a 20 year recorded low of 11°C to a high of about 18°C. The pipeline passed under a number of small rivers and one large river with a 20 year low of 5°C.

(e) Pour point, viscosity and yield data would be available only from laboratory trials conducted by pour point suppliers. Because the McKee crude is a complex rheological system, it was anticipated that laboratory data would vary based upon the particular laboratory undertaking the work, instruments used to carry out the measurements and the various additives available.

With these constraints, the pipeline designers considered both 100 NB and 150 NB diameter lines, with the latter being chosen to satisfactorily meet all design requirements and maintain a good level of flexibility.

Following are the main features of the pipeline design:

(a) The hydraulic calculations had to be based on a range of values which reflected the various laboratory predictions as a preferred pour point depressant had yet to be identified. This was further compounded by the shear thinning nature of the crude. The variation in viscosity measurements and the design viscosities adopted are given in Fig. 2. Viscosity measurements ranged from 4 to 20 cp at 66°C, 7 to 30 cp at 21°C and 50 to 190 cp at 11°C.

(b) The pipeline was designed for shear rates which corresponded to throughputs from 5000 BOPD to 12 000 BOPD.

(c) The pumping facilities for 6000 BOPD consisted of a suction booster pump and a multistage centrifugal shipping pump with 100% standby for each unit. The piping arrangement allowed for series operation of the shipping pumps to provide higher pressures after extended pipeline shutdowns.

(d) The hydraulic design showed that the pumping pressure was not only sensitive to capacity, but also to the assumed viscosity. For this reason, it was necessary to use a pump with a sufficiently flexible design curve to cope with the wide range of viscosities predicted in the laboratory.

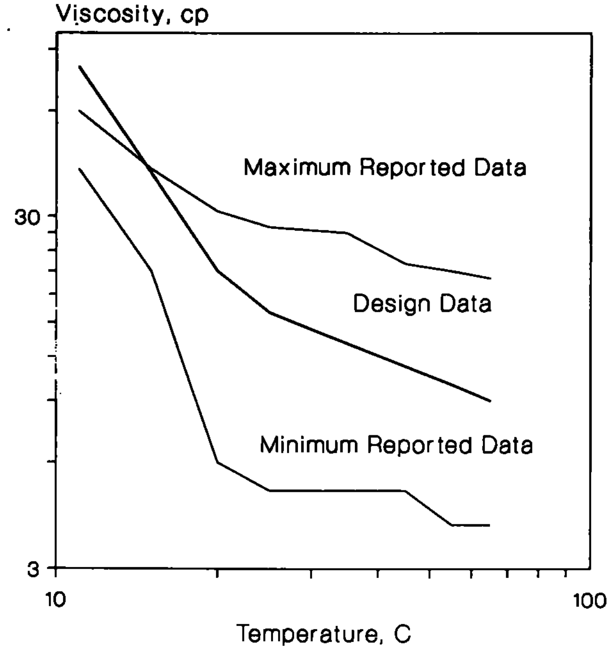

Fig. 2: Actual versus Design viscosities 5500 BOPD.

(e) Yield values were measured by the pour point depressant suppliers' laboratories which resulted in the pipeline being designed for a yield value of 4.0 Pa for the crude at 11°C.

(f) Storage tanks at the inlet to the pipeline provided for 3000 bbl of intermediate storage between the production process plant and the pipeline to minimize the need for frequent shutdowns.

(g) Considerable attention was paid to the need for turbulent operation to minimize or prevent wax crystal deposition in the pipeline. The use of regular (initially daily) pigging to remove wax caused either by dropout or by deposition on the pipe wall was included in the design.

(h) The pour point depressant injection system provided for substantial storage, the tank was heated to allow for the use of pour point depressant products which had above-ambient melting points and which had to be added to the crude at elevated temperatures. Injection was between the booster and shipping pumps to ensure the pour point depressant was well mixed into the crude. This limited use to those pour point depressants which were stable under high shear.

(i) In addition to the mainline block valves at the start and end of the pipeline, additional block valves, high pressure injection valves and check valves were installed at spacings which ranged from 6.5 km to 10.5 km.

This design concept allowed the mainline pumps to be able to restart the pipeline flow provided the crude yield value remained at or below 4 Pa. In the event that the crude yield increased above 4 Pa, then high pressure injection pumps with low capacities could be used to inject condensate at the block valve stations. If the crude yield value did not exceed 41.3 Pa, then a high pressure injection pump would be able to restart the flow without exceeding the allowable pressures for the ANSI 600 pipe.

LABORATORY STUDIES FOR SELECTING THE POUR POINT DEPRESSANT

Laboratory studies for selecting the most suitable product were undertaken by a number of supplier laboratories. This section of the paper describes the studies for the product currently in use.

Two types of pour point tests were used to evaluate potential pour point depressants. The first type followed the procedure described in ASTM D97-66.

The second type of pour point test was a modified version of ASTM D97-66 in an effort to duplicate predicted pipeline cooling rates. Prior to each test, the ambient crude sample was reheated to a bottom-hole temperature equivalent of 85°C and held there for one hour. This thermal pre-treatment was assumed to destroy any thermal history and restore the crude oil to its original pour point condition. The *beneficated* samples were allowed to cool to 65°C, pour point depressant added, the samples stabilized and then cooled according to the predicted pipeline cooling profile shown in Table 2.

Several pour point depressants were tested with Additive A giving the most significant reduction in pour point. The summary in Table 3 show that 2000 ppm of Additive A was able to reduce the pour point to 11°C using the modified cooling curve.

Based upon the results of the pour point screening, Additive A was chosen for rheological studies.

Apparent viscosity

Viscosity/temperature studies were conducted under dynamic test conditions using the predicted cooling curve shown in Table 2. Each sample was beneficated as described previously. Several shear rates were used to indicate the shear-thinning (pseudoplastic) behaviour of the crude. The dose temperature was 60°C at several dose rates.

Time (hours)	Temperature (°C)
0	65
1	44
2	32
3	25
4	20
5	17
6	15
7	14
8	13
9	12
10	11
11	9

Table 2: Predicted pipeline cooling rate.

Dose rate, ppm	ASTM, °C	Modified, °C
0	30	30
400	28	20
800	24	18
1200	22	14
1600	20	13
2000	18	11

Table 3: Comparison of pour point tests.

Based upon the test results, a dose rate of 2000 ppm of Additive A was chosen for pipeline commissioning. This dosage rate would be reduced as flow conditions in the pipeline stabilized. Table 4 shows the viscosity of the crude treated with 2000 ppm of Additive A at shear rates of 8, 16 and 40 sec-1 at varying temperatures. The viscosity/temperature relationships are shown graphically in Fig. 3.

Yield values

It was anticipated that the yield value would vary along the length of the pipeline with the two extremes being:

(a) The crude oil at the start of the pipeline which cooled statically from 65°C to 11°C.

(b) The crude oil at the discharge end of the pipeline which has been cooled dynamically (under shear) to 11°C.

Using the predicted cooling curve in Table 2, one sample was cooled statically (no shear) to 11°C and held for 12 hours at that temperature. Another sample was cooled dynami-

	Viscosity, cp		
Shear rate, s-1	8	16	40
Temperature °C			
43	4	2	3
38	4	2	4
33	4	3	4
28	4	4	5
23	7	7	6
18	26	12	13
13	56	34	25
11	86	46	35

Table 4: Viscosity temperature studies.

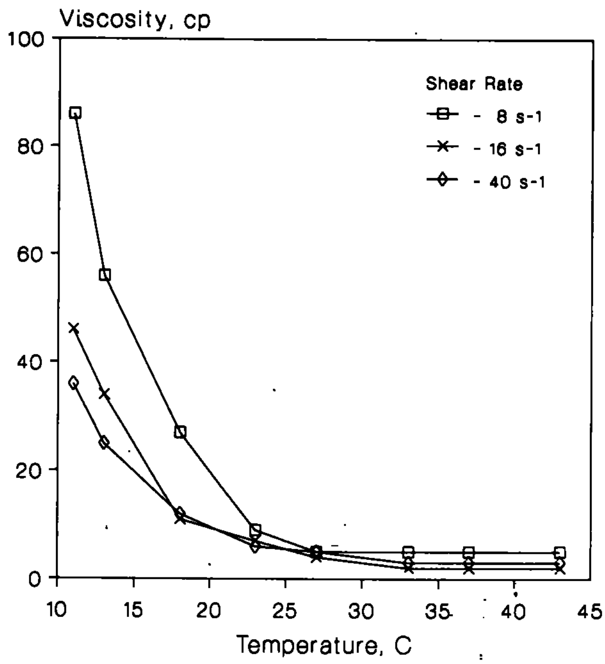

Fig. 3: Laboratory studies: viscosity vs temperature.

cally at 8 sec-1 to 11°C and held for 12 hours at that temperature. Yield values obtained using 2000 ppm of Additive A after static and dynamic cooling conditions were 3.5 Pa and 2.5 Pa, respectively.

Application of laboratory data

The laboratory data, from three laboratories, was used in the design of the pipeline. The yield data resulted in the pipeline being designed for the crude having a maximum yield value of 10 Pa under normal conditions. The apparent viscosity data adopted for design (Fig. 3) is a compilation of all such data obtained during the laboratory studies.

PIPELINE COMMISSIONING

On November 5, 1984, crude began flowing into the production station storage tank. At this time, the pour point depressant was being injected into the crude tank inlet line. When the storage tank was almost full, the pour point depressant injection was shifted to its design position, between the booster and shipping pumps. Pour point depressant was initially injected at 2000 ppm into the crude.

When the first crude arrived at the Omata tank farm testing showed it to have excellent rheological properties and a pour point of below 5°C. The pour point and rheology of the pipelined crude was monitored on a 24-hour basis for the next seven days.

Results obtained during the commissioning period showed that the pour point depressant performed significantly better in actual pipeline conditions than in laboratory testing. By closely monitoring pipeline pressures, crude rheology and pour points, it has been possible to reduce the pour point depressant dose rate to much lower levels than initially.

REVIEW OF DESIGN

Following commissioning, it has been possible to review the performance of the pipeline using a pour point depressant in the crude to determine the extent to which the laboratory trials and pipeline design were applicable to this situation.

The only major design factor which has not been reviewed is the restart of the pipeline after an extended shutdown which would reflect the reliability of yield value predictions.

This is simply because there have been no extended shutdowns and, quite obviously, it is hoped that this parameter will never be tested.

Pour point

The pour point of the crude is measured both to meet sales specifications and as an input to the pipeline management plan, in order to determine the pour point depressant dose rate. The pour point is measured in the storage tanks at Omata to ensure that the crude meets the sales specifications.

During initial operation of the pipeline, the pour point was measured strictly in accordance with ASTM D97-66. It rapidly became evident that this was not the most suitable method of measuring pour point as the results of this test were giving pour points greater than the *actual* pour point of the crude both at pipeline discharge and in the bulk tank.

From both a pipeline management viewpoint and sales requirement, the *actual* pour point is of more interest since in both cases the true requirement is for a crude that can be transported by pipeline from a bulk tank at 15°C without going solid. The test was amended for our use by deleting the requirement to reheat the crude prior to the test as this was obviously destroying the previous temperature and shear history of the crude. The use of pour point depressant has exceeded laboratory predictions with *actual* pour points of less than 5°C being easily obtained at acceptable dosage rates.

Hydraulic design

The pumping pressures required to transport the crude in the pipeline have been substantially less than those predicted. During 1985 pressures of 246 psi were required to transfer 5000 BOPD whereas values of 350 psi had been predicted. Today 300 psi is required to transfer 10 900 BOPD whereas a value of 450 psi had been predicted. The only significant variable likely to have changed for the first example is the apparent viscosity with the reduction in pumping pressure representing a reduction in average apparent viscosity of around 50%. By today a second variable, namely a warming of the ground and thus higher average temperature has also affected pump capacity.

Temperature profile

The design was based on a calculated temperature profile along the pipeline which was used in both the laboratory simulations for viscosity determinations and in the pipeline design. Fig. 4 shows the temperature profiles in 1985 and today compared with that which has been estimated based on temperature measurements at sampling points.

The major difference in 1985 was in the sudden cooling caused by river crossing which has had a far greater effect than that predicted. This has probably had an effect on the wax crystal growth and thus may explain some of the variances in viscosity and pour point. More recently warming of the ground in the vicinity of the pipeline has significantly affected the pipeline temperature profile.

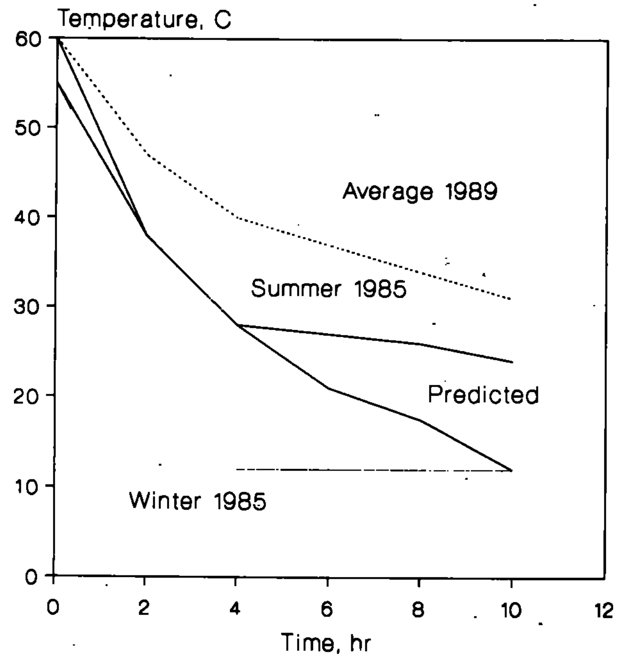

Fig. 4: Temperature profile: Actual vs predicted.

Restart after short shutdowns

Following shutdowns ranging from a few hours to days, it has been possible to restart the pipeline using only the shipping pumps with restart pressures no higher than normally encountered.

Mechanical design

The mechanical design of the pipeline has been excellent with the following features having been noted:

(a) The installation of sampling points is essential for monitoring of performance so that *actual* pour points and temperatures can be measured.

(b) Pressure monitoring is essential for estimating viscosity and detecting the passage of undosed slugs of crude.

Logistical implications

The use of chemical pour point depressant required that adequate stocks of a high value product be maintained. With an offshore supply route, this can mean that substantial working capital is tied up in the product. In addition, the operation is totally dependent on the availability of the pour point depressant and it is impossible to continue production without it.

Deposition or settling

The design of the pipeline and selection of a pour point depressant had not included detailed consideration of wax deposition on the pipeline walls or to wax settling under laminar flow. The experience of the pour point depressant suppliers combined with some laboratory work indicated this was not a major problem. Provision for continuous pigging was, however, included in the management plan for the pipeline.

Examination of pigs has shown that wax buildup is not a major problem, provided sufficient pour point depressant is injected with the dose rate being a function of ground temperature. As the ground temperature falls, the rate of wax deposition increases and additional pour point depressant must be added to overcome this.

The pipeline operation has seldom been in laminar flow, other than for short durations, and it has not been possible to evaluate the effects of wax settling during laminar flow.

Pour point depressant dose rate

The laboratory simulations had indicated that a dose rate of 1200 ppm would be required to achieve a pour point of 15°C (sales specification) and 2000 ppm to achieve 11°C this being the minimum winter ground temperature. At these dose rates the yield values and viscosities had also been measured. The following observations can be made about the dose rate of pour point depressant:

(a) Overall a lower dose rate over design or calculated, is required to achieve an actual pour point of 11°C. The pour point is usually 5°C at these dose rates.

(b) The dose rate has to be varied from summer to winter which reflects the changing ground temperature and thus the cool-down rate and pipe wall temperature.

(c) The controlling factors in determining the dose rate are wax deposition on the pipe wall, which increases as temperature drops, and *actual* pour point at the pipeline discharge.

PIPELINE MANAGEMENT PLAN

As a result of a number of year's successful operation, a plan for operating the pipeline has been developed to reflect the various parameters described in this paper. The main features of this plan are as follows:

(a) The pipeline is continuously pigged to remove wax buildup. Inspection of the pig determines the degree of wax deposition on the pipe wall which becomes one input in determining the PPD dose rate.

(b) The temperature of the crude is measured on an intermittent basis at the various sample points along the line. This is being done both to improve the knowledge of the actual pipeline cooling rate and as a minor input to determining the pour point depressant dose rate.

(c) The pour point of the crude is measured on a daily basis at the pipeline discharge to provide a direct feedback on pour point depressant performance which is used as a major input in determining the pour point depressant dosage rate.

(d) The pour point of the crude is measured in the stock tanks to ensure compliance with sales specifications and to provide an indication of any long-term trends in pour point which can be used in assessing the dose rate.

(e) The pipeline pressures at the start of the line and at various intermediate points are measured and recorded on a chart recorder. Alarms are installed to alert operators of any sudden problems. The pressures are used as an indication of viscosity or restrictions in the line.

(f) For normal operations, the pour point depressant dose rate is determined by considering the following factors:
   (i) Sufficient pour point depressant must be added to maintain the actual pour point in the bulk tanks at 15°C.
   (ii) Sufficient pour point depressant must be added to keep wax deposition within acceptable limits. The aim is to have minimal wax buildup on the pigs.

(g) For long-term monitoring of performance, the actual pour points in the bulk tank and at sampling locations, as well as pumping pressures, can be used to modify the normally accepted dose rates.

(h) The approach to pipeline shutdowns depends on whether or not the shutdown is planned. For planned shutdowns, the dose rate is increased to 2000 to 2400 ppm for about 8 hours to lower the pour point as much as possible, and flow rates are held to a maximum to ensure that wax deposition is minimized. The bulk storage tank at the pipeline inlet is maintained as full as possible and sufficient space is held at the discharge end of the line to accommodate this volume. Depending on the duration of the shutdown, if known, the line is then pumped intermittently at high rates (9000 BOPD) for between 20 minutes and one hour. Under this regime, the restart pressures do not change significantly from the normal operating pressures.

   If an unplanned shutdown of a duration longer than one day was to occur in the future, the approach will be to apply this same procedure as closely as possible. Pour point depressant would be injected at a high rate and the pipeline would be *kicked* at high velocities for a short period of time as often as possible.

(i) The dosage of pour point depressant must be continuously monitored to ensure that pipeline operation without pour point depressant does not occur. Despite motor interlocks, a flow switch and flow meter, there has been one instance of zero injection rate for a few hours. This occurred because the flow meter was out of service for repair, the flow switch failed and the pump relief failed to shut causing pour point depressant to be recycled around the pump.

CONCLUSION

From the foregoing it can be seen that the field is being successfully produced using a range of relatively simple, low technology, cost effective techniques without having specialist in-house expertise and sophisticated equipment.

Petrocorp envisage at this early design stage of Waihapa to use similar technology.