Available Methodologies Concerning the Treatment and Removal of Sand From Pipelines and Associated Case Studies

Neil Mackay, Halliburton House

Summary

Traditional sand-management programs usually consist of several measures employed to mitigate the production of sand from wells, a process commonly referred to as sanding. Such systems include production prediction and monitoring, topside management, sand control, and "intelligent" systems (Gherryo et al. 2009). Sand control can be considered in terms of short- and long-term solutions; examples of long-term solutions (preventative measures) would be the application of gravel packs, screens, inflow control devices, and chemical stabilization methods (Abney et al. 2007). In instances where a sand-management program has not been employed or has been ineffectively delivered, sand can and is deposited in pipelines/riser systems. This can be a gradual process of continual minor deposition over time, or systems can be overwhelmed with a sudden influx of sand as a consequence of formation or completion failure. The result leads to increasing pipeline resistance, reduced flow rates, rising pressure drop in the pipeline system, and erosion, which, in turn, can lead to degradation of the pipeline/riser and topside systems (Abney et al. 2007). The main focus then concerns the short-term sand-control solution of remediating the pipeline system with the goal of removing the deposits. An operator might wish to pursue a sand-removal/cleaning program with the specific goal of performing an in-line inspection as part of an integrity-management scheme.

This paper discusses the available methodologies for remediation of a pipeline affected by sand and presents examples where the discussed methodologies have been applied.

Introduction

Before attempting to solve operational issues, the problem must be fully understood. Gathering as much relevant information as possible is an essential prerequisite for defining and engineering an effective solution. Regarding sand removal from pipelines, the expected data required would typically include

- Detailed pipeline geometry
- Historical production flow rates, pressures, and compositions
- Installation P&IDs (with particular attention to existing pigging facilities, separator systems, and available equipment laydown area)
- Pigging history (if any)
- Pipeline production and debris samples
- Operator information about expected deposit production from specific wells (helps identify the presence of multiple types or quantification of pipeline debris).

There are a few design considerations that will determine the final methodology, such as whether the remediation operation is to be performed during production, how the received sand/debris is to be handled, and whether the desired operating parameters can be achieved with respect to transport velocities and propulsive power required to support the proposed methodology

Two primary methods of sand removal that form the basis of the cleaning operations are discussed: progressive pigging and/or the utilization of debris transport gel (DTG). Central to both is the use of pipeline "pigs." Pigs can be described as solid or semisolid fluid-driven entities that are pumped through a pipeline from one point to another where launching and receiving facilities exist. These are used for a wide variety of applications.

Progressive pigging and DTG can be applied unilaterally or in combination. This is usually influenced by the fill media and deposit type, volume, and distribution within the system. If the sand is contaminated with hydrocarbon and/or wax, then chemical treatments might also be adopted at various stages of a remediation operation. These could include

- Organic solvents to dissolve and disperse wax deposits
- Surfactants to alter wettability, aid solvent treatment, and deposit mobility
- Inorganic solvents to dissolve and disperse possible scales.

Sand, in the context of this paper, is used to describe unconsolidated solid particulate debris deposited in the pipe.

Progressive Pigging

Progressive pigging is generally run in a controlled manner with a number of pigs with increasing aggressive characteristics through a pipeline. The volume of material received/collected with each pig is carefully monitored at the receiving pig trap, pit (usually onshore), or tanks, and is used to guide the selection of the following pig types that are subsequently run. Progressive pigging would typically be undertaken in instances where there are no available pigging records, where uncertainties exist regarding deposit volumes/distribution (often the case with sand removal), where there is a lack of cleaning history, and where there are any other potential mechanical intrusions/restrictions that may exist.

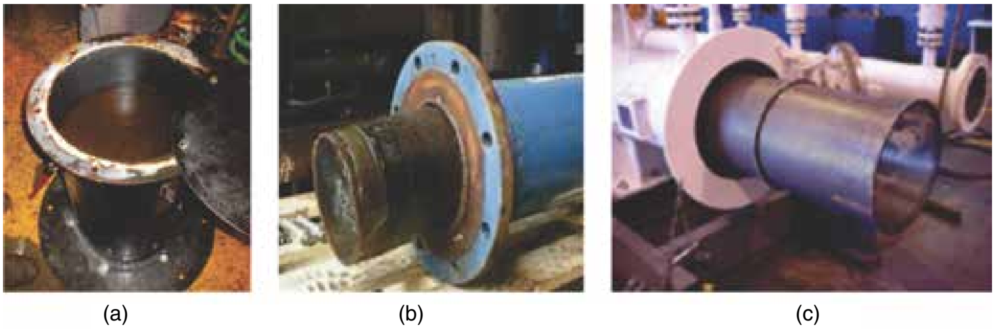
It is necessary to first use a pig that is capable of traversing the pipeline and the expected deposits within it. Initial risk exists without detailed information regarding debris type and distribution.

Gel Pigs. It is likely that, when dealing with a pipeline containing sand deposits, a gel pig might be the first to be used. The term "gel pig" is often used to describe a short length of substantially cross-linked elastic solid within the pipeline, of which the composition and parameters differ for corresponding applications. In this instance, the term relates to a semisolid gel cylinder, similar in length to a solid-bodied pig **(Fig. 1).** These gel pigs are usually precast and supplied in a canister, which can be designed for attachment to the pig launcher.

Gel pigs have been used extensively and successfully in the past and can traverse (usually fairly short) lines, which can have varying inner diameters (IDs). They are sometimes used to segregate par-

---

Original SPE manuscript received for review 22 May 2012. Paper (SPE 163052) peer approved 27 June 2012.



(a) (b) (c)

Fig. 1—(a) Gel pig in canister, (b) gel pig in receiver, and (c) gel/foam pig "catcher."

cels of chemical treatments and gels (of the DTG type) necessary for the operation.

While gel pigs might not displace much debris, this is not always their primary purpose. Their successful transition through the pipeline serves as a good indication to proceed to the next stage of a progressive pigging program. Furthermore, with respect to loose debris, such as waves of sand, gel pigs can level out the deposit, enabling better chemical treatment penetration. These features mean that gel pigs are often selected as the initial pig in a campaign; however, they are not without limitations.

In gas-filled pipelines, they are only effective when the rigidity of the gel is sufficient to resist the effects of gravity. Gel pigs can only be formed up to a maximum diameter of approximately 24 in.; beyond this diameter, they tend to "slump" because of their own weight. This, in turn, reduces the effectiveness of their seal and increases bypass, which could drastically affect the batching of chemical treatments and debris transport gels. In liquid systems, gel pigs can be considered to be largely neutrally buoyant.

They are limited in terms of wear resistance, and their effectiveness in long-range operations (especially when used in dry lines) is severely compromised.

In theory, alterations could be made to the gel formulation to make the pigs less dense and more rigid. This, in turn, would allow the manufacture of larger gel pigs but would require the addition of solid "blowing agents," which, in many applications, might not be desirable.

Foam Pigs. The next stage following receipt of gel pigs would be to use foam pigs. Where gel pigs are not practical or necessary, foam pigs can be substituted.

Foam pigs were designed and conceived for lines where changes in ID exist or large volumes of deposit are expected. Foam pigs are chemically blown open-cell polyurethane; the open cell nature results in a permeable material that will become saturated with the media used to propel the pig, and foam pigs are therefore effectively neutrally buoyant in most liquids. The density of the foam can be altered by the addition of more or less of the blowing agent. Foam is typically produced in the range of 2 to 10 lb/ft^3; typically, 2- and 5-lb/ft^3 materials are the most commonly adopted. The lowest-density foam pigs (2 lb/ft^3) are "sponge-like" in nature and therefore able to reduce significantly in size. They also have the lowest tear strength (approximately 2 lb/in.), so they possess a risk of breaking up in a system. Where such a concern exists, a pig catcher (Fig. 1) can be used in mitigation. Foam pigs can be used to remove sand initially or increase confidence in the transit capability of more aggressive pigs, which would then remove the sand.

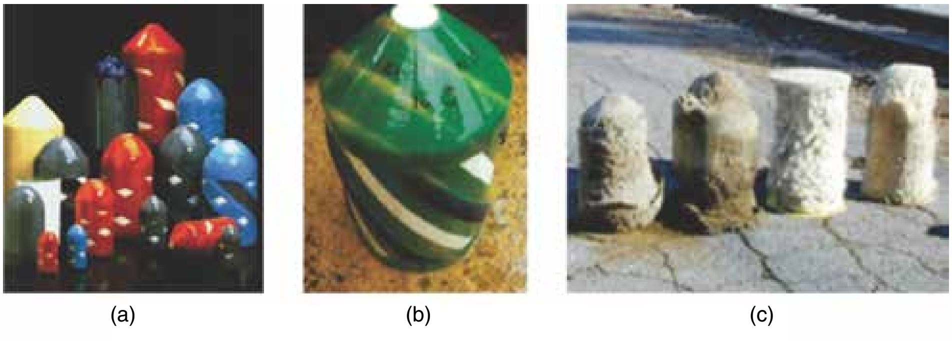
Foam pigs are gradually increased in aggressiveness by altering some or a combination of the following parameters:

- Density [can be dual density (e.g., low density outer layer and higher density core)]
  - Low, 2 lb/ft^3
  - Medium, 5 to 8 lb/ft^3
  - High, 8 to 10 lb/ft^3
- Diameter
- Coating
- Addition of brushes, blades, scrapers, and studs

Fig. 2 illustrates an assortment of foam pigs.

Solid-Bodied Pigs. After successful receipt of foam pigs in good condition with little return of debris, solid-bodied pigs can then be deployed. Solid-bodied pigs are heavier (and usually substantially negatively buoyant in use) and offer better sealing capabilities, and a large range of items can be attached to the mandrel to aid in debris removal/cleaning. The first run with a solid-bodied sand-removal pig should be made with reduced guide diameters, more compliant seals, and usually without additional cleaning elements to increase the pig's ability to ride over debris, therefore reducing the potential of creating a blockage.

The most commonly used metal-bodied pig is the bidirectional (Bi-Di) pig **(Fig. 3).** The main perceived advantage of the Bi-Di pig, as its name suggests, is that it can be run in both directions along the pipeline. This is advantageous because it provides some mitigation against the occurrence of a "stuck pig" caused by an accumulation of debris. Bi-Di pigs can be applied to some dual-



(a) (b) (c)

Fig. 2—(a) Assorted foam pigs, (b) a foam brush pig, and (c) damaged foam pigs post operations.

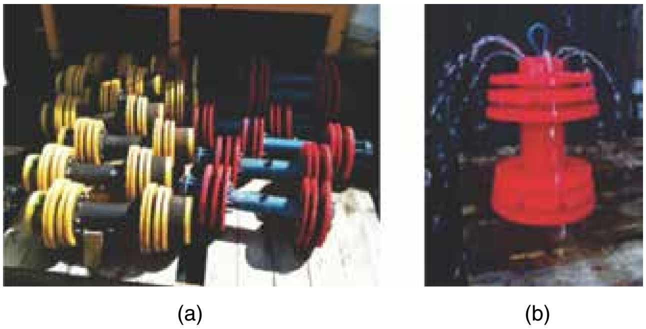

(a) (b)

Fig. 3—(a) Bi-Di pigs and (b) a cup brush pig and solid-cast Bi-Di jetting-head pig.

diameter pipelines as long as the changes in ID are compatible with respect to pig design. Above 20% variance in ID can be risky, and trials are usually recommended before operations.

Often, before the running of Bi-Di pigs in a progressive pigging program, cup and conical seal pigs would first be used. They are unidirectional and ideal for applications under low pressure. Their main advantage with respect to progressive pigging is the reduced risk of becoming lodged because of the lower cleaning performance and "lift-off" effect of the cups where they encounter debris within the pipeline. Their seals are "energized"; the pressure behind them helps maintain the seal. As such, it is unlikely that these seals will flip. A standard cup pig seal offers up to 5% reduction in ID, whereas a conical cup seal can reduce as much as 20% **(Fig. 4).**

As is the case with most pigging operations, there is a degree of forward bypass and slippage. Each configuration has advantages and disadvantages, depending on the operation. Forward bypass is created by the effective gap between the seal element and the pipe wall; this is obviously increased as the pig traverses debris or obstructions that lift the sealing element from the pipe wall. As a consequence, heavy deposits that are overridden (slippage) will result in increased bypass. This bypass is, in some cases, advantageous in mobilizing and maintaining a suspension of debris. In this mode, forward bypass and slippage mechanisms are correlated.

If forward bypass is desired, irrespective of seal function, this can be engineered into the design of the pig by the use of carefully sized bypass ports and jetting features aimed locally toward the pipe wall. This creates localized turbulence in front of the pig and higher superficial velocities near the pipe wall, aiding lifting and suspension of sand, and mitigating against a "bulldozer effect" **(Figs. 5 and 6)** and potential bridging of debris. Forward bypass

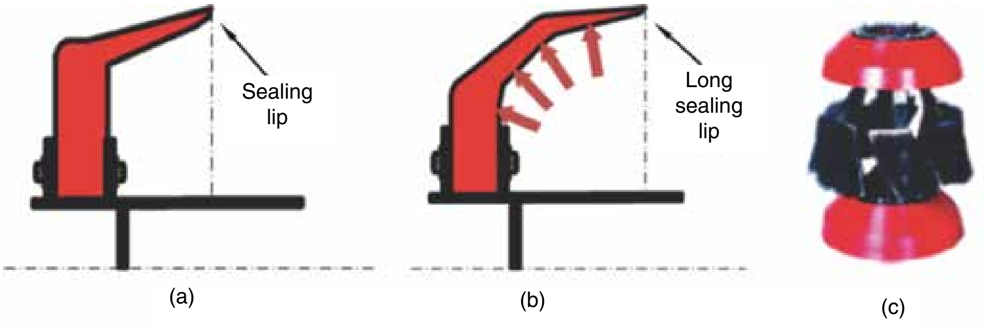


Fig. 4—(a) Standard cup pig seal, (b) conical cup pig seal, and (c) conical cup brush pig.

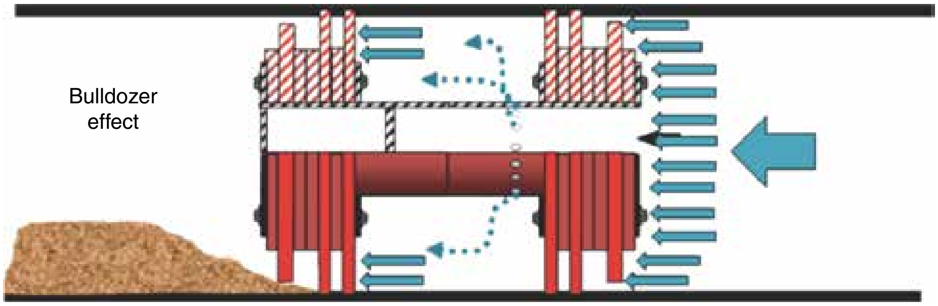


Fig. 5—Pig with rear seal pack bypass in transit through pipeline (without jetting head).

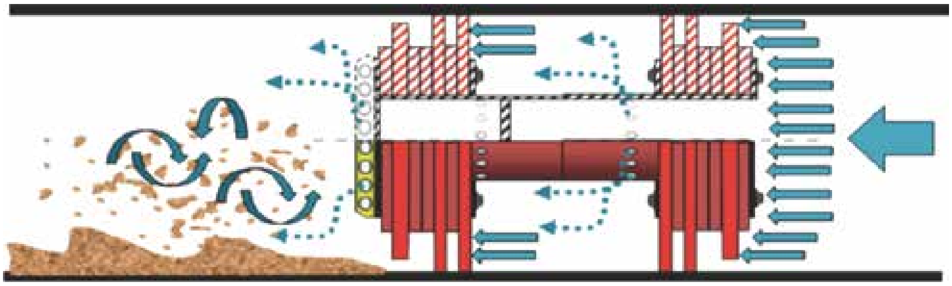


Fig. 6—Pig transiting pipeline with rear seal-pack bypass and jetting head.

Fig. 7—Articulated pig; front-sealing module followed by brush modules at rear.

is also important in maintaining lubrication and wear on the seals in longer pipelines (see the section on debris transport gels). However, by introducing forward bypass, less flow is available to drive the pig, so the design must incorporate the correct ratio of bypass/and the required driving flow.

Pigs can also be articulated so that the more aggressive cleaning elements can be pulled through the system by a "tractor" module that is not an aggressive cleaner but is able to seal and negotiate line obstacles that would not be possible otherwise **(Fig. 7).**

Pig Decision Tree. Having an appreciation for the cleaning performance capability of the pigs and the stage of the progressive pigging program at which they might be used is essential for engineering and implementing an effective program. The pig decision tree/process map is a tool that is developed and supplied by the project to help personnel proceed prudently during the operation (i.e., on what pig to run next) **(Fig. 8).** Ideally, actual process measures (numbers or ranges of values) should be added to define what constitutes wear, damage, or debris in terms of light and heavy (acceptable/manageable or unacceptable/unmanageable volumes) trigger values that would permit escalation of the pigs aggression.

The same pig or pig type (class) requires being run/rerun as long as it produces desirable results, as monitored at the receiving processing facility. When a particular type and size of pig ceases to be effective (i.e., little or no debris is received and a level of confidence for running each pig class has been achieved), the next pig class can be considered.

For example, when low-density bare foam pigs yield no further debris removal, a higher density foam pig with appropriate cleaning accessories attached/built in can be used. Another example for the next step, depending on the particular case, might be to use a batching/cleaning pig with flexible seals that conforms to the inside of the pipeline and any linings.

The left half of Fig. 8 (Diagram 1) outlines a generic planned progressive pigging program, each pig more aggressive than the last and rated under a class system (in red). The right side of Fig. 8 (Diagram 2) details the assessment that should be performed on receipt of each pig from Diagram 1. The assessed factors are

- Pig condition intact
- Pig condition, wear of pigs, sealing and guide discs/cups (progressive lack of abrasion)
- Run time for pigs
- Quantity of sand manageable
- Quantity of liquids manageable (gas pipeline specific)

If the pig is received with signs of damage, then the last successful pig would be run. If received intact, it is assessed for wear. If abnormally over- or underworn, then the field engineer can refer to Diagram 3 **(Fig. 9).**

A decision to continue with the next pig class, return to the last pig class, or modify/upgrade the pig within its current class should

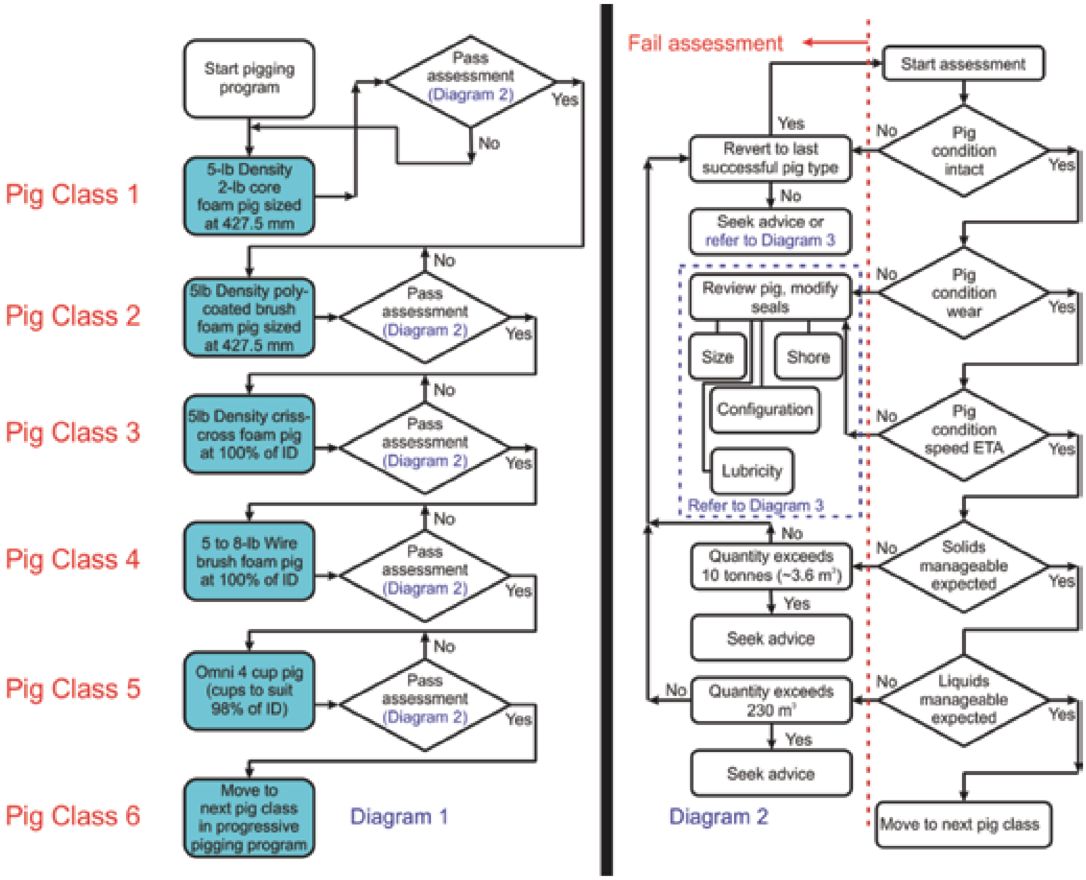


Fig. 8—Pig decision tree Diagrams 1 and 2.

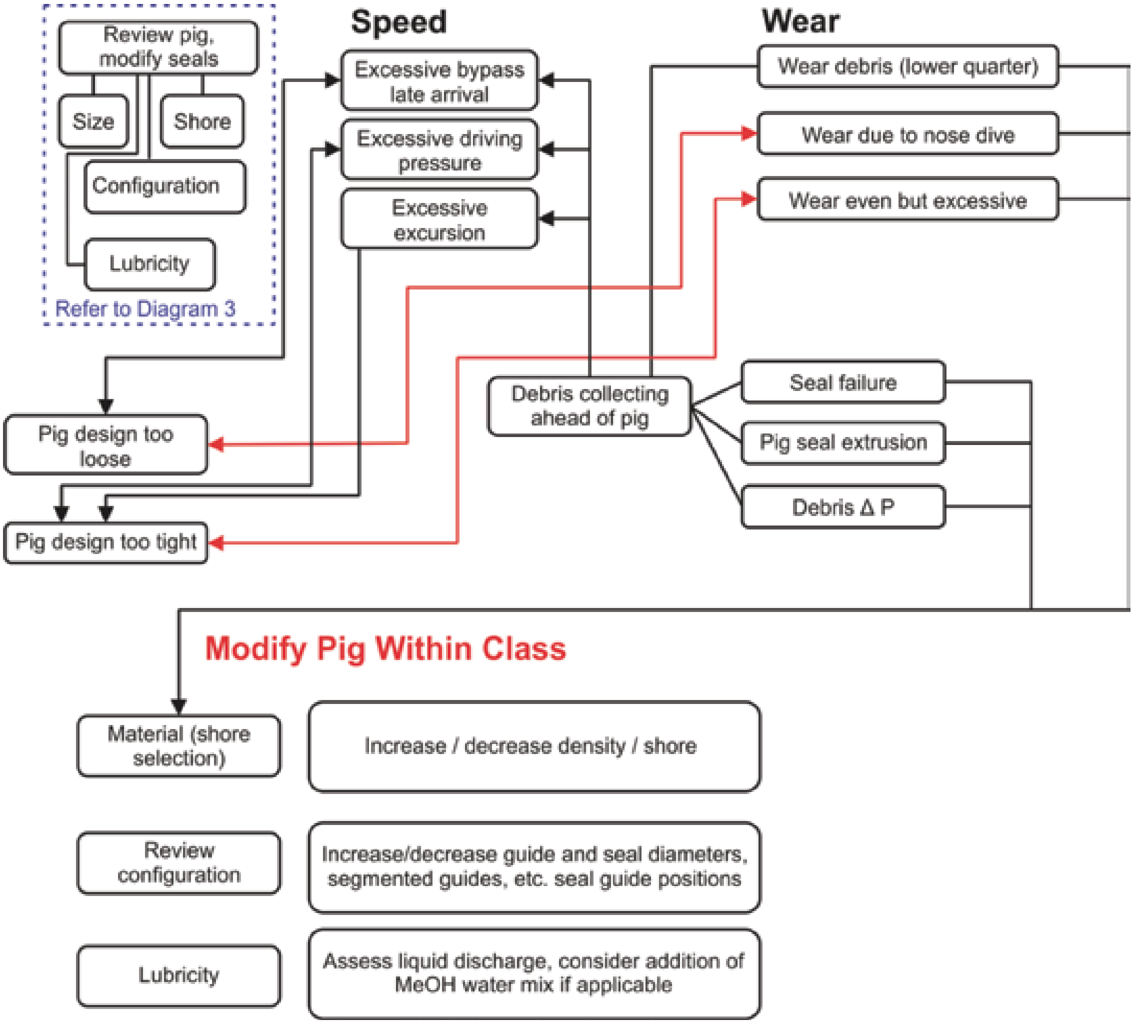


Fig. 9—Pig decision tree Diagram 3.

be made on the basis of the information available. For example, within the same pig class, one may increase shore hardness of the seals/guide discs on a Bi-Di and run again. The decision tree would be designed and altered for a particular operation on the basis of what information and surety there is for the existing system condition. The pigging program would continue until little or no debris was being displaced from the line.

Debris Transport Gel

Gels can be used successfully for transporting solid debris from pipelines and can provide significant advantages for debris transport over long distances under low-velocity conditions. Gels are not only effective in transporting loose material, but can be (and often are) used with pigs to effectively remove commonly encountered pipeline deposits. They have an inherent ability to lift and hold in suspension debris, sweeping it out of a line. Some gels are excellent at holding sand under static conditions for a long period of time or indefinitely, while others require mixing to help prevent debris settling.

This is usually the difference between a "linear" or "crosslinked" gel **(Fig. 10).** These terms relate to a gel's properties as a result of its formulation. A polymer is mixed with a base fluid to create a linear gel, of which the individual polymer chains interact linearly with

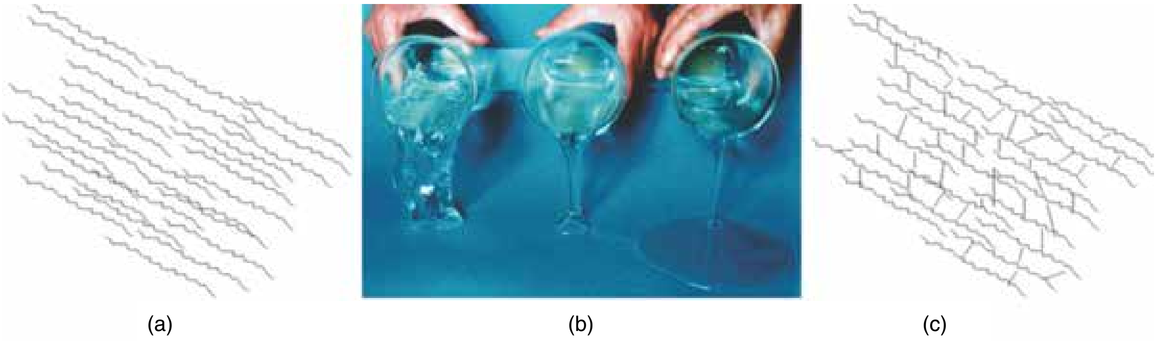


Fig. 10—(a) Linear gel structure, (b) gels from high to low viscosity (left to right), and (c) crosslinked gel structure.

TABLE 1—SAND-LOADING CAPACITY FOR A 60-LB/1,000-GAL GEL

Gel System	Sand Loading (kg/m³)	Day 1	Day 2	Day 3	Day 4	Day 5
60 lb/1,000 gal	120	Sand in suspension	Sand in suspension	Sand in suspension	Sand in suspension	Sand in suspension
	240	Sand in suspension	Sand in suspension	Sand in suspension	Sand in suspension	Sand partially suspended
	480	Sand in suspension	Sand in suspension	Sand partially suspended	Sand partially suspended	Sand partially suspended
	720	Sand in suspension	Sand in suspension	Sand settled completely	Sand settled completely	Sand settled completely
	960	Sand in suspension	Sand settled completely	Sand settled completely	Sand settled completely	Sand settled completely
	1200	Sand in suspension	Sand settled completely	Sand settled completely	Sand settled completely	Sand settled completely

one another, and is measured by means of its viscosity and polymer loading (e.g., 50 lb/1,000 gal, meaning 50 lbs of polymer per 1,000 gallons base fluid). A crosslinker, which can be solid or liquid, can then be added to the liner gel, which alters the chemical composition, giving rise to a 3D structure which significantly increases the viscosity or produces a semisolid material.

The gel formulation would be designed according to the requirements of the operation. The typically required information to produce a “design brief” for a gel formulation inludes the following:

- Sand particle size range and overall volume to be removed
- Constraints and requirements of gel volume to be used for the operation
- The achievable velocity for running the cleaning train
- If any stoppages are expected
- Whether online/offline sand removal is required

Generally, however, the combination of a linear gel with pigs at higher flow rates (approximately 1m/s) works effectively for sand removal, as described in Case History 1.

Sand Suspension/Carrying Capacity of Gel. A service company has conducted multiple trials to examine the sand-carrying capabilities of different formulations of gels. Recent trials considered the type and loading of polymer, application of crosslinkers, and also studied the velocities required to pick up and carry sand within a system.

Table 1 presents the tabulated results from one of many experiments showing the sand carrying capacity (sand particles ≤ 150 microns) of a linear 60-lb/1,000-gal gel with a viscosity of 46 cp. The table indicates the carrying capacity of the gel in laboratory experiments.

As can be seen in Table 1, after 24 hours, the gel was able to hold up to an equivalent of 1,200 kg of sand per m^3 of gel. If there is an interruption to cleaning processes for more than 24 hrs (e.g., perhaps during a stuck-pig scenario), then the sand would in theory drop out of suspension. At this high loading, this could create a significant problem, as the sand would then be concentrated in the pipeline section equivalent to the length of the gel train. A crosslinked gel can have greater suspension capacity than the linear gel trialled and presented in Table 1. However, it will require greater and sometimes unpractical flow rates to pick up the sand (generally approximately 2 m/s). The key factor is achieving the correct balance between the sand-carrying/-loading capability of the gel (allowing for potential stoppages or a stuck pig) and the gel’s capacity to pick up the sand, which is ultimately determined by the gel rheology, transit velocity, and wall turbulence.

Gel Formulation, Turbulence, and Viscosity. DTGs formulated from polymers and crosslinkers are non-Newtonian fluids, meaning that they exhibit a change in viscosity, which is dependent on the shear rate and shear stress applied to them.

Where laminar flow regimes exist and the rheology is known, computer models can be constructed relatively straightforwardly. However, to remove sand from a pipeline, the gel or fluid (sometimes water/oil) is required to be within a turbulent flow regime to pick up sand from the near-wall region. The sand is then transferred by means of wall turbulence into the core of the gel or fluid. The gel/fluid’s ability to maintain the sand in suspension is then essential. Exact numerical simulation of turbulent fluid flow in real space is virtually impossible to model. However, simulations in a plane of flow can be achieved, and there are other empirical methods that can be used (e.g., direct numerical simulation in 2D). This method uses empirical approximations based on trial and experiment to give an understanding of: the transition between laminar and transitional flow, the nature of wall flow in terms of shear, boundary layer depth (sublaminar layer) behavior, and an indication of wall turbulence in non-Newtonian fluids [such as those used for sand removal gel **(Figs. 11 and 12)**].

When a mixed gel formulation flows, the rheology can change within the body of the fluid under the influence of localised areas of shear; this, in turn, can be used to influence the transition between laminar, transitional, and turbulent flow regimes in gels at a given average flow velocity. The formulation must be thick enough (from the addition of polymer) to suspend sand but exhibit sufficient turbulence at the wall and an appropriately small sublaminar layer at the applied velocity to be capable of mobilizing the sand at the surface of the deposit or pipe wall.

For example, as the apparent viscosity or, if appropriate, the yield point (the minimum shear required to induce flow) increases, the core flow becomes increasingly laminar and viscous. This then can prevent the sand from transitioning between the turbulent area in the near-wall region to the core, which is essential for effective sand pickup.

From left to right, the circles represent the cross-sections of a fluid flow modeled as a Newtonian fluid, a power law fluid (can be shear thinning, shear thickening, or Newtonian), and two Herschel-Bulkley (HB) fluids, which are power law fluids with a yield stress applied to them, and can be considered to be equivalent to a highly viscous, and possibly crosslinked, gel (Rudman and Blackburn 2005).

The simulations in **Figs. 13 and 14** are for a Carreau-Yasuda fluid, which shows similar behavior to that of the HB simulation results and also suggests transitional flow (Rudman and Blackburn 2005).

What is clear from these simulations is that non-Newtonian fluids, if too viscous or if not exhibiting the correct properties under shear, can operate under laminar flow conditions in the core

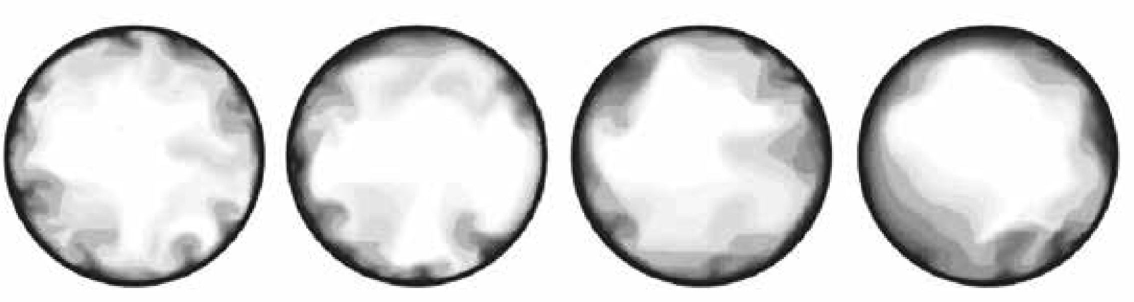


Fig. 11—Instantaneous contours of axial velocity; white contours are high velocity and black are low (Rudman and Blackburn 2005).

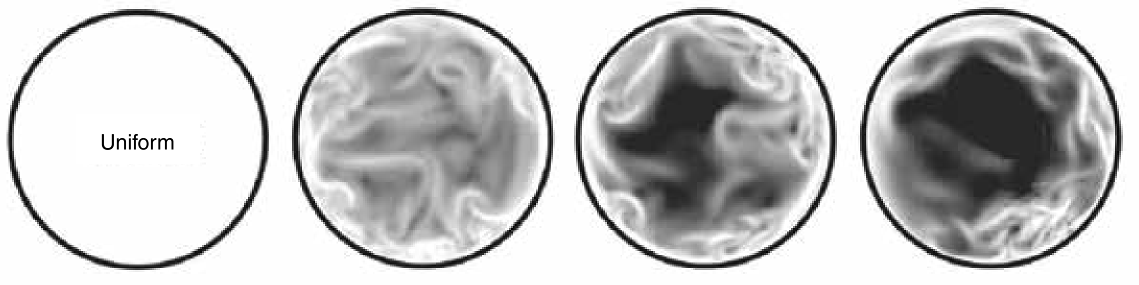


Fig. 12—Viscosity; white contours are low viscosity and black are high (Rudman and Blackburn 2005).

of the fluid, which is not ideal for sand removal. When laminar flow occurs in the core of the fluid and turbulent flow at the pipe wall, it becomes much more difficult for the sand to enter into the core. It can seem as if the laminar flow almost resists it. Additionally, particles seem to more easily drop out of laminar flow regimes.

Optimum Gel Velocity for Sand Removal. As non-Newtonian fluid dynamics with respect to polymers and gels is not yet an exact science, the easiest way to determine the required velocity to pick up sand is to first select a gel thought to be suitable for the application (using previous data/experience as a guide) and trial it in conditions as best as can be replicated.

For the sand-removal operation (Case History 1), some trials were performed in this manner before operations. Sand of particle size ≤400 microns was inserted into a smaller pipeline in volumes proportional to that expected in the real-life case, which was calculated in terms of the % area.

Gel was then displaced through the pipeline driven by a foam pig and water at different velocities. There was a volume of cross-linked gel ahead of the linear gel. This was in place to create an in-

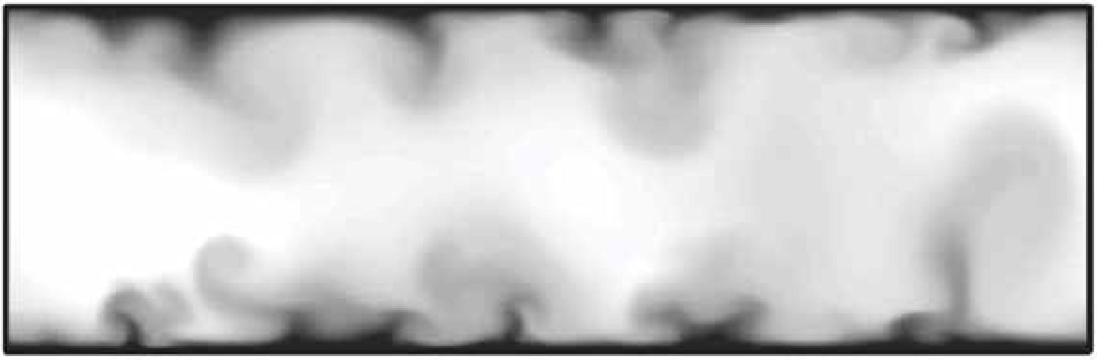


Fig. 13—Instantaneous contours of axial velocity; white contours are high velocity and black are low (Rudman and Blackburn 2005).

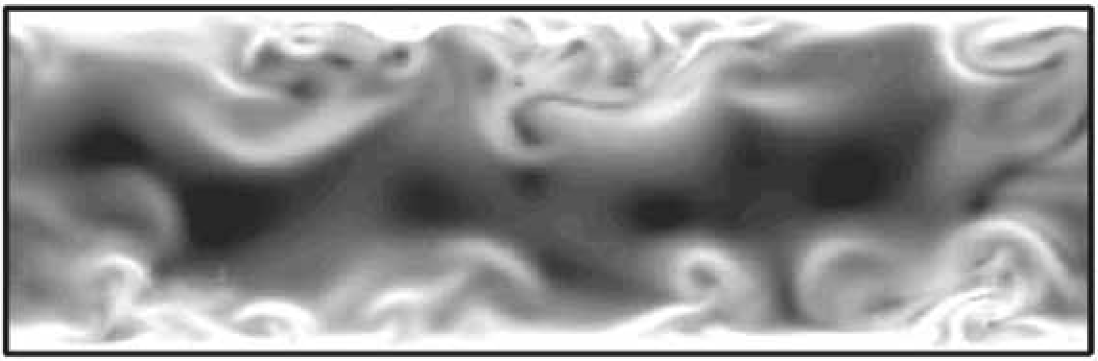


Fig. 14—Viscosity; white contours are low viscosity and black are high (Rudman and Blackburn 2005).

TABLE 2—SAND REMOVAL TRIALS RESULTS

Pig Run	Volume of Crosslinked Gel (L)	Total Volume of Gel (L)	Volume of Sand in 10-in. Pipeline (L)	Fluid Velocity (m/s)	Sand Remaining Post Run (L)	Observations and Comments
1	50	200	21	0.5	~20	The gel/water passed over the sand in the spool piece with little disturbance to the geometry of the sand because of the low fluid velocity.
2	50	200	21	1	0	Water picked up some sand initially. Gel and pig followed and picked up the remainder, leaving a clean spool piece/pigging loop.
3	50	200	42	1	0	Run 3 showed same results as Run 2

terface between the gel and the water fill within the pipeline, and not for the purposes of sand removal.

The results showed that, to remove the sand from the pipeline, the velocity of the formulated gel (50 lb/1,000 gal) with a small volume of crosslinker (to maintain the gel as slug) needed to be greater than 0.5m/s and potentially as much as 1m/s, as pig runs were only performed at these velocities, with a failure to remove the sand at 0.5m/s and successful attempts made at 1m/s. The trials effectively proved that velocity is an essential factor for sand removal.

Oil-Based Gel. In instances where a water-based gel is not suitable or for online cleaning (e.g., stabilized crude pipeline), the technology exists to continually mix and gel production oil. The gelling agents are spiked into production flow proportionally for maximum effective gel formulation. A diffuser can be required to aid mixing, which can be positioned in the pig launcher. Often, production rates are sufficient to effect removal of the sand using this technique.

This gel technology allows an almost immediate viscosity increase and is easily controllable through injecting the gel components, and the resultant gel is stable up to any temperature found in a typical product transfer line (135°C).

The gelled oil can be "broken" by introduction of a breaker chemical at the receiving end or introduced during mixing, enabling easier extraction of sand and recovery of production fluids.

Case History 1

Case History 1 details a recent operation wherein the service company successfully removed a large volume of sand from a pipeline in preparation for an in-line inspection using a magnetic flux leakage (MFL) intelligent pig.

The pipeline in question was 16 in. in diameter, 20.9 km long, and on commencement of operations contained an estimated volume of at least 380 tonnes of sand. A nonintrusive "pressure-pulse" survey was performed several months before the operation on the line, the results of which provided an estimate of the location and volume of deposits contained within the pipeline.

Some trials were performed with the selected sand-removal gel (50 lb/1,000 gal, approximately 33 cp) to determine if it would be suitable for removal of sand (with particle size ≤400 microns) at ~1m/s,which was calculated as the maximum achievable velocity expected during the sand-removal operation. Results from the trial are displayed in **Table 2.**

Immediately before operations, an additional pressure-pulse survey was performed, the results of which estimated that as much as 500 tonnes of sand existed within the pipeline.

The pipeline was flushed through with water to remove the bulk of in-situ hydrocarbon, followed by a chemical cleaning train consisting initially of a solvent followed by a surfactant. The solvent inclusion was designed to thin any oily residue remaining within the pipeline. The purpose of the surfactant was to help "lift" residual oil from the sand. The treatment volume was determined with respect to the velocity (0.25 m/s) to allow a 10-minute contact time **(Fig. 15).**

Two gel trains were then performed, as is shown in **Figs. 16 and 17.**

After each of the runs, a pressure-pulse survey was performed, followed by a foam brush pig run before use in the following two gel trains **(Fig. 18).** This is a good example of an effective process measurement that aids the progressive pigging operation.

The third and fourth gel trains were identical to one another and, on completion, a final pressure-pulse survey was performed, confirming the removal of sand from the pipeline. Once all the pressure-pulse data had been analyzed, the results indicated that the remainder of the sand had been removed on Gel Train 2. **Table 3** summarizes the success of the gel at removing a larger volume of sand than expected using less gel than allocated, and used at a prescribed velocity of 1 m/s.

Once the results from the pressure-pulse survey were analyzed, indicating the removal of sand from the pipeline, it was successfully returned to production, and Bi-Di pigs were sent through the pipeline. They collected a mixture of wax and oily residue from the pipe wall **(Fig. 19).** A final run with a Bi-Di and gauge plate with no damage or significant wax/debris allowed the team to proceed with sufficient confidence in running a successful intelligent pigging tool

The basis of this operation was the use of debris transport gel to remove sand. Additionally, the operation also contained elements of progressive pigging—gel pigs were initially used during the chemical cleaning train. In addition to possessing the correct properties at this stage of the operation, use of the gel pigs distributed the sand, aiding in

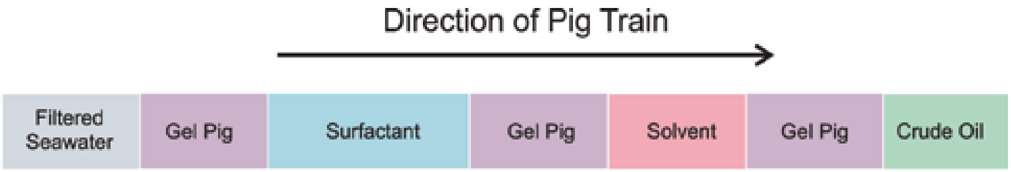


Fig. 15—Chemical treatment pig train.

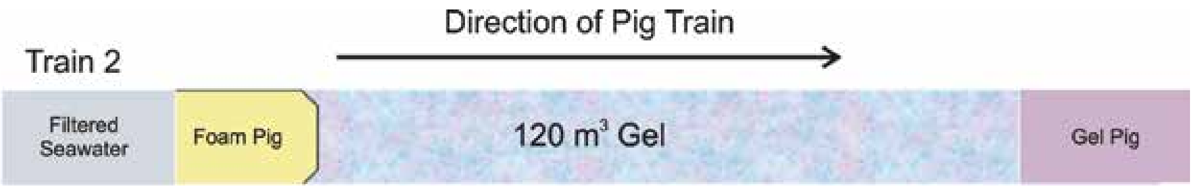


Fig. 16—First gel pig train.

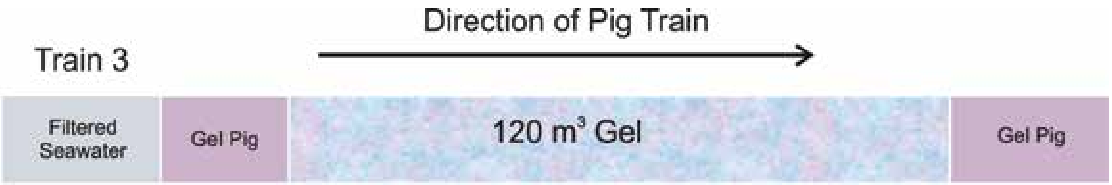


Fig. 17—Second gel pig train.

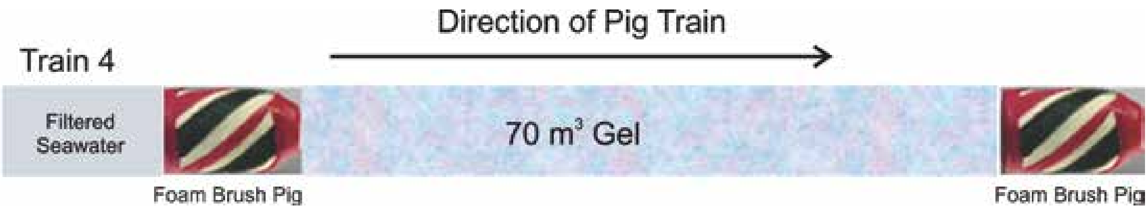


Fig. 18—Third and fourth gel pig trains (identical).

TABLE 3—SAND REMOVAL SUMMARY

Estimated Sand, Months Before Operation	Estimated Sand Volume on Operation Commencement	Available Gel	Gel Used	Actual Volume Required to Remove Sand	Sand Loading Capacity of Gel
~380 tonnes	~500 tonnes	400 m^3	380 m^3	240 m^3	~2083.33 kg/m^3

- Cleaning, especially in reference to the surfactant, which was then able to penetrate more easily into the sand, removing hydrocarbons
- Ease of pickup for the following gel trains

The foam brush pigs used in the gel trains were followed by gradually more aggressive Bi-Dis (in terms of their diameter), which were run on production before the in-line inspection. The job was successful because of the following factors:

- Trial and selection of an effective debris transport gel
- Chemical treatment to wash sand, aiding in pickup and disposal of sand on receipt
- Use of progressive pigging principles

Case History 2

Case History 2 details an operation wherein the service company successfully removed more than seven tonnes of sand and some liquid from a 20-in. (16-km) gas pipeline in preparation for an in-line inspection using a MFL intelligent pig.

Instead of using a debris transport gel, such as the one applied to the sand removal program in Case History 1, a progressive pigging campaign was undertaken **(Fig. 20).** This was deemed sufficiently effective because it was known that suitable volumes of liquid holdup were produced during normal production for the expected volumes of sand, which were significantly lower in proportion to the volumes removed in Case History 1.

Fig. 19—Wax/oily deposits returned by means of the Bi-Dis post-sand removal.

(a) (b)

Fig. 20—(a) Pigs 5, 6, and 7 in the progressive pigging program and (b) the MFL tool before mobilization.

The campaign consisted of 12 pigs in total and removed 7.233 tonnes of sand and 712 m^3 of liquid.

Table 4 is a tabulated summary of the operation and illustrates a good representation of information analyzed throughout the campaign to decide the best course of action regarding the next step. This is a textbook example of increasing the aggressiveness of the pig as less debris is received until finally running a profile pig. Where profile pigs or "dummy tools" are employed, they have the same parameters as the intelligent pig but none of the expensive equipment/measuring capabilities. While it acts as a trial run for the real thing, it also serves the purpose of a final cleaning pig. In this case, the profile pig returned 200 kg of sand and 304.2 m^3 of liquid, compared to the previous pig, which yielded <5 kg of sand and 15m^3 of liquid. The intelligent pig was run without incident in the first pass, indicating a successful cleaning operation, which can be attributed to an excellent execution of progressive pigging techniques.

Case History 3

Case History 3 details an operation wherein the service company successfully removed between 25 and 37 tonnes of sand from a 24-in., 143-km-long crude oil trunkline. During a routine pigging operation, a Bi-Di pig became stuck approximately 300 to 600 m from the launcher, resulting from an unexpected accumula-

TABLE 4—PROGRESSIVE PIGGING PROGRAM RESULTS SUMMARY

Pig No.	Pig Type	Launched	Received	Amount of Fluid Received (m^3)	Pig Condition	Description and Amount of Debris (tonnes)
1	5-lb Bare foam	20:00 17/11/04	03:00 24/11/04	296.6	Good, small piece missing at front	1.596 tonnes of fine sand contaminated with BETX and NORM (Total for 1st and 2nd pig)
2	2-lb Bare foam	00:20 23/11/04	03:00 24/11/04	0	Broken into three large pieces	
3	5-lb Criss-cross	19:30 24/11/04	09:30 25/11/04	18	Good lost 40% of coating, possibly because of pig trap insert	1.4364 tonnes of fine sand contaminated with BETX and NORM
4	Steel body cup pig	09:40 26/11/04	22:30 26/11/04	14	Very good	1.0773 tonnes of fine sand contaminated with BETX and NORM, some coating debris from criss-cross pig and metal from a spiral wound gasket
5	Bi-Di	17:55 27/11/04	04:00 28/11/04	10	Very good	1.418 tonnes of fine sand contaminated with BETX and NORM
6	Bi-Di	14:00 28/11/04	22:00 28/11/04	1.4	Very good	0.85 tonnes of fine sand contaminated with BETX and NORM
7	Bi-Di brush	17:40 1/12/04	20:45 1/12/04	7.8	Very good	0.54 tonnes of fine sand contaminated with BETX and NORM with some rags
8	Bi-Di brush	12:35 3/12/04	21:30 3/12/04	33	Very good	<100 kg fine sand contaminated with BETX and NORM
9	Bi-Di magnetic	12:50 4/12/04	19:15 4/12/04	12	Very good	5 kg fine sand contaminated with BETX and NORM (magnets were clean)
10	Bi-Di gauge	12:45 5/12/04	18:00 5/12/04	15	Very good, small nick on gauge plate	<5 kg fine sand contaminated with BETX and NORM
11	Profile pig	15:15 19/12/04	01:30 20/12/04	304.2	Very good	200 kg fine sand contaminated with BETX and NORM
12	MFL tool	22:40 20/12/04	03:30 21/12/04	0	Generally very good; Odometer wheel damaged	<5 kg fine sand contaminated with BETX and NORM

TABLE 5—PROGRESSIVE PIGGING RESULTS

Pig No.	Pig Type	Pig Diameter (in.)	Purpose of Pig	Result
1	Medium-density foam pig	20	Redistribute high deposits within pipeline	Pigs received in good condition with no sand returned
2	Medium-density foam pig	20	Redistribute high deposits within pipeline	
3	Medium-density foam pig	24	Remove sand, prove piggability	Various pressure spikes encountered, pigs ruptured
4	Medium-density foam pig	24	Remove sand, prove piggability	

Fig. 21—Once-through sand removal gel train.

TABLE 6—SAND-REMOVAL AND SAND-CARRYING CAPACITY OF GEL

Volume of Gel Used	Minimum Volume Sand Removed	Maximum Volume Sand Removed	Minimum Sand Loading	Maximum Sand Loading
~223 m^3	24.5 tonnes	37 tonnes	110 kg/m^3	161 m^3

tion of sand caused by low flow velocity and infrequent operational pigging.

The pig was retrieved and the service company was contracted from this point forward to remediate the pipeline. Initially, a progressive pigging program was undertaken. The progressive pigging results are presented in **Table 5.**

Extensive trials were performed on various potentially suitable gels, some results of which are contained in the previous section on the sand-carrying capacity of gel. The gel exhibiting the best properties for the operation was selected and the pig train designed **(Fig. 21).**

The gel used was designed to have a higher viscosity than usual because it was expected that the gel would be diluted slightly by means of forward bypass of water. The sand-removal and sand-carrying capacity of the gel is presented in **Table 6.**

Note that the loadings in Table 6 are average loadings over the total volume of gel used when removing between 24.5 and 37 tonnes of sand. The highest measured loading was that of the first sample taken on receipt of the first pig, which yielded 448.46 kg/m^3. As the samples were taken at intervals, it is possible that higher loadings were experienced. As gel was received and additional samples taken, the loading values steadily declined. This shows that the gel was more than capable of handling the volume of sand experienced. The success of this job therefore can be attributed to

- Careful selection of gel using information gathered from
  - Trials
  - Results and interpretation from initial progressive pigging program
- Effective pig-train design

Conclusions

In cases where sand-management programs have not been implemented or ineffectively delivered, sand deposition can occur in pipelines, requiring remediation. This paper details the different methods by which sand can be removed from pipelines and the technical considerations contained within each to help ensure a successful operation. The efficient documentation of knowledge and experience gained from previous sand-removal operations is valuable when defining and designing operations. Experimental investigation with respect to gel formulation (e.g., sand pickup velocity or sand-carrying/suspension capacity of gel) proves important, not just to the present operation, but also for future operations. The conclusions made are evident from the case-history examples, which illustrate that the effective use of sand-removal methodologies were sufficient and can be used synergistically where a more complex engineering remediation solution is required.

Acknowledgments

The author thanks Allan Browne, Jim MacLennan, Laurence Abney, and Halliburton for permission to publish this work.

References

Abney, L., Browne, A., and Croley, R. 2007. Pipeline Debris, Short-Term and Long-Term Solutions. Presented at Pipeline Rehabilitation & Maintenance 2007, Manama, Bahrain, 9–13 December.

Gherryo, Y., Shatwan, M., Qui, K. et al. 2009. A SystematicApproach to Sand Management. *World Oil* **230** (8).

Rudman, M. and Blackburn, H.M. 2006. Direct numerical simulation of turbulent non-Newtonian flow using a spectral element method. *Appl. Math. Modell.* **30** (11): 1229–1248. http://dx.doi.org/10.1016/j.apm.2006.03.005.

Neil Mackay is a Technical Professional with Halliburton Pipeline and Process Services in Aberdeen, primarily concerned with the pipeline-remediation aspect of the business. He works on a consultation basis for Halliburton's remediation projects, has traveled globally presenting company technologies, and is involved in international operations where required. To date most of his experience has been in sand/wax removal. He is currently undertaking further learning at the Robert Gordon University in Aberdeen toward chartered status, which he expects in 2014. Mackay holds a BEng degree in mechanical engineering from Heriot-Watt University.