PRESSURE WAVE ANALYSIS STREAMLINES PIPELINE PIGGING

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1. Introduction

Pipelines are used in many industries to transport a wide variety of fluid—from water, crude oil, petrochemical products, and hydrocarbon gases to multiple combinations and phases of these products. Because pipelines deliver product to where it is needed, they are important to the continued operation of vital industrial infrastructure or domestic supply, and their shutdown can have significant consequences, conceivably of national or even international importance. Because of the nature of the products pipelines transport, debris can build up over time, causing bore restrictions or full blockages (Figure 1). The development of bore restrictions causes reduced flow and higher backpressure, ultimately limiting throughput delivery of the product; if allowed to develop unchecked, they can block the pipeline, preventing the flow path completely. The most common method for removing debris from pipelines is using pigs/scraper tools and chemical additives, which can be costly with potentially high risks, possibly blocking a pipeline if the pig becomes stuck as a result of accumulating debris. Cleaning campaigns can be lengthy and costly because of the need to minimise the potential risk of pipeline blockage and subsequent shutdown, considering that avoiding such an event is a priority for operators, both in terms of production loss from the pipeline and potential ensuing effects for any downstream facility using the product as well as the additional efforts necessary to remediate the issue.

Figure 1. Examples of debris restrictions

The answer to remediating any deposit issue is an explicit understanding of what is causing the restriction so that the solution can be effectively and accurately targeted. This lack of knowledge creates uncertainty during the planning and implementation of the cleaning campaign because of having to minimise the potential risk of causing a pipeline blockage. This can manifest itself as an overly cautious approach to a pigging campaign whether by performing too many pig runs or using less aggressive pigging tools than would ideally be used if a detailed knowledge of the pipeline contents was known. Both these approaches require additional costs, time, and resources to execute the campaign, which could be deployed more effectively in a different manner to gain the best results for the pipeline remediation. Further, knowledge optimises pipeline chemical treatments, whether in combination with a pigging campaign or as a standalone treatment.

2. State-of-the-Art Technologies Available for Deposit Assessment

There are currently multiple technologies available on the market for deposit assessment of a pipeline. However, as with any technology, there are limitations to each method. Each can add value in terms of development and tracking of a pipeline cleaning campaign, though the value, and effort, and resources necessary to gain information varies significantly amongst these technologies. Table 1 shows some of the existing technologies available along with advantages and disadvantages of each method.

Technology	Advantages	Disadvantages
Thermal, ultrasonic, and other external scanning imaging	• Accurate • Nonintrusive	• Localised measurement • Time consuming for long system • Access constrained • Resource requirement
Debris mapping pigs/calliper pigs	• Accurate • Whole pipeline measurement	• Access constrained • Intrusive • Potential risk of blockage • Time • Resource requirement
Camera inspection	• Visual and easily interpreted	• Access constrained • Intrusive
Theoretical modelling	• No operational requirement	• Only theoretical and based on assumptions
Pressure and flow monitoring	• Minimal operational requirement	• Basic knowledge gained

Table 1. Advantages and disadvantages of current deposit profiling technologies

Table 1 reveals a significant issue affecting many of the existing technologies—access to the pipeline—whether this is because of the requirement to physically insert a tool when it could lack access points, such as pig traps, into the pipeline or to access it externally when it could be buried or subsea. Of these access-restrained methods, the best-case scenario is using a debris mapping tool because this provides an accurate picture of the debris throughout the entire pipeline, though the potential risk of running a pig in a pipeline, of which little is known, is extremely risky. Theoretical modelling and pressure and flow monitoring methods can be regarded as desirable because they have little impact on pipeline operation; however, they only provide information that is either overly basic or uncertain. Ultimately with these technologies, the pipeline operator should balance the potential risk versus reward with these methods to determine which, if any, to choose.

3. Pressure Wave Analysis

3.1. Theory

The first step to determining the deposit profile of a pipeline using pressure wave analysis is to understand the acoustic velocity for the contents of the pipeline while accounting for the pipeline operating parameters. Using this information, the acoustic velocity can be calculated using a modified Hooke's law formula (Equation 1) (Chilingarian, Robertson, and Kumar 1987):

$$c_{system} = c_{fluid} \sqrt{\frac{1}{1 + \frac{ID}{WT} * \frac{K}{E}}} \quad \text{.......... (1)}$$

Once the restrained acoustic velocity is known, the Darcy-Weisbach equation (Equation 2) determines the frictional pressure drop, thereby obtaining a time-log of pressure change for the pipeline, as measured per Wallis (1969):

$$\Delta f = \frac{f}{2} * \frac{\Delta L}{d} * (p * u^2) \quad \text{.......... (2)}$$

Then this calculates the hydraulic diameter throughout the length of the surveyed system (Gudmundsson 2006).

3.2. Data Collection

Data collection is performed by connecting an ultra-high-speed data logger recording at an equivalent 4,000 data points per second with a sensitivity of 0.15% at either the inlet or outlet end of the pipeline placed in a stable flowing state with no significant pressure fluctuations. Once this is confirmed, the data logger is set to record the pipeline pressure, the pulse is generated, and pressure variations are monitored and recorded to produce a signature (Figure).

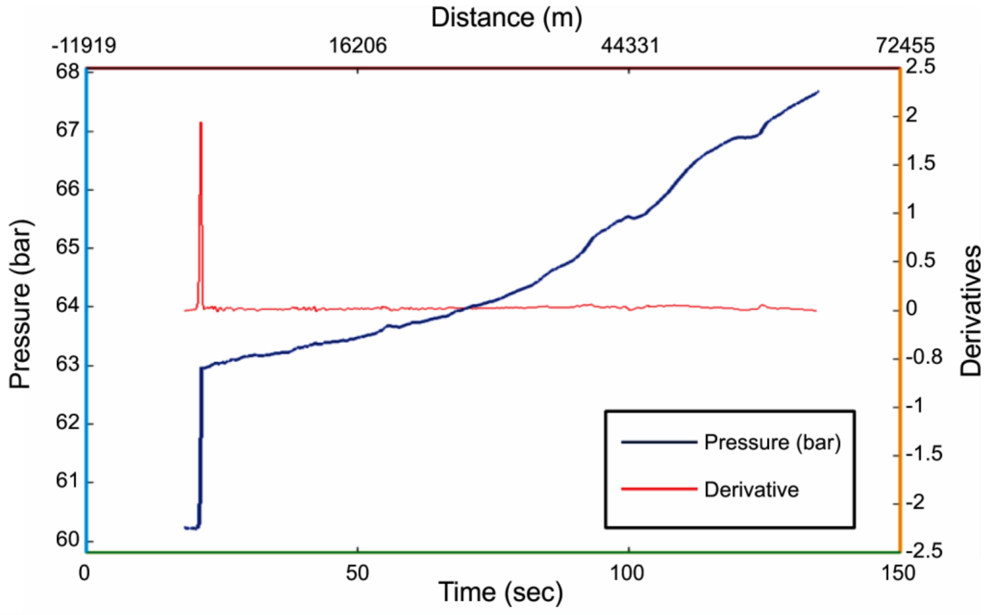

Figure 2. Pressure signature

The pulse is created by operating a quick-closing time valve at the same location the data logger is connected, therefore retarding flow and creating a fluid hammer or pressure wave within the pipeline. The valve closed to generate a pressure wave is kept closed during the survey. The wave traverses the pipeline to the end point, then reflects and travels back to the pressure transducer point where the valve can be opened and normal production resumed (Figure 3). Various data sets are collected to help ensure repeatability.

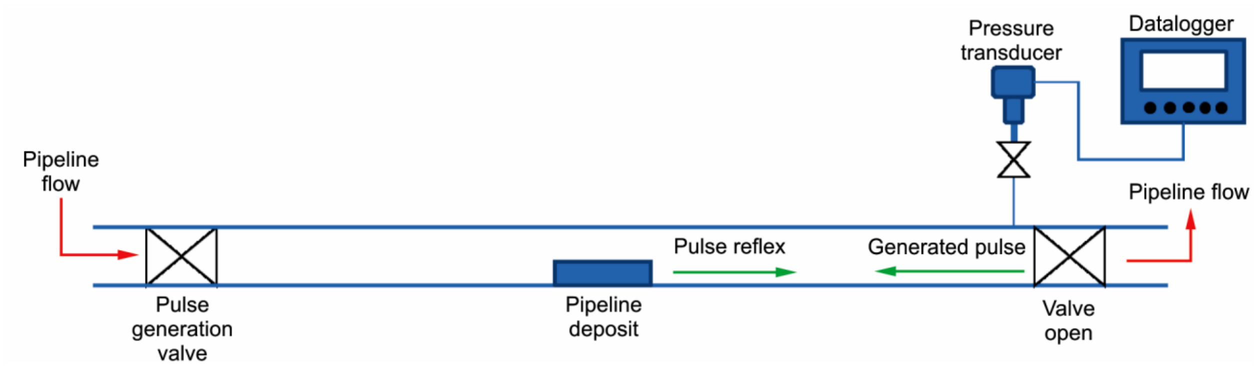

Figure 3. Typical debris-profiling data collection setup

3.3. Analysis

The data sets are normalised, compared for repeatability, and checked for anomalous readings. After abnormal data sets are discarded, the remaining ones are analysed individually using proprietary software, following the process flow in Figure 4. Data collected from the field are compared to the simulated model of the pipeline designed using details provided by the operator on the fluid and system. The deposit profile and pipeline internal bore are then extrapolated using numerical iterative algorithms.

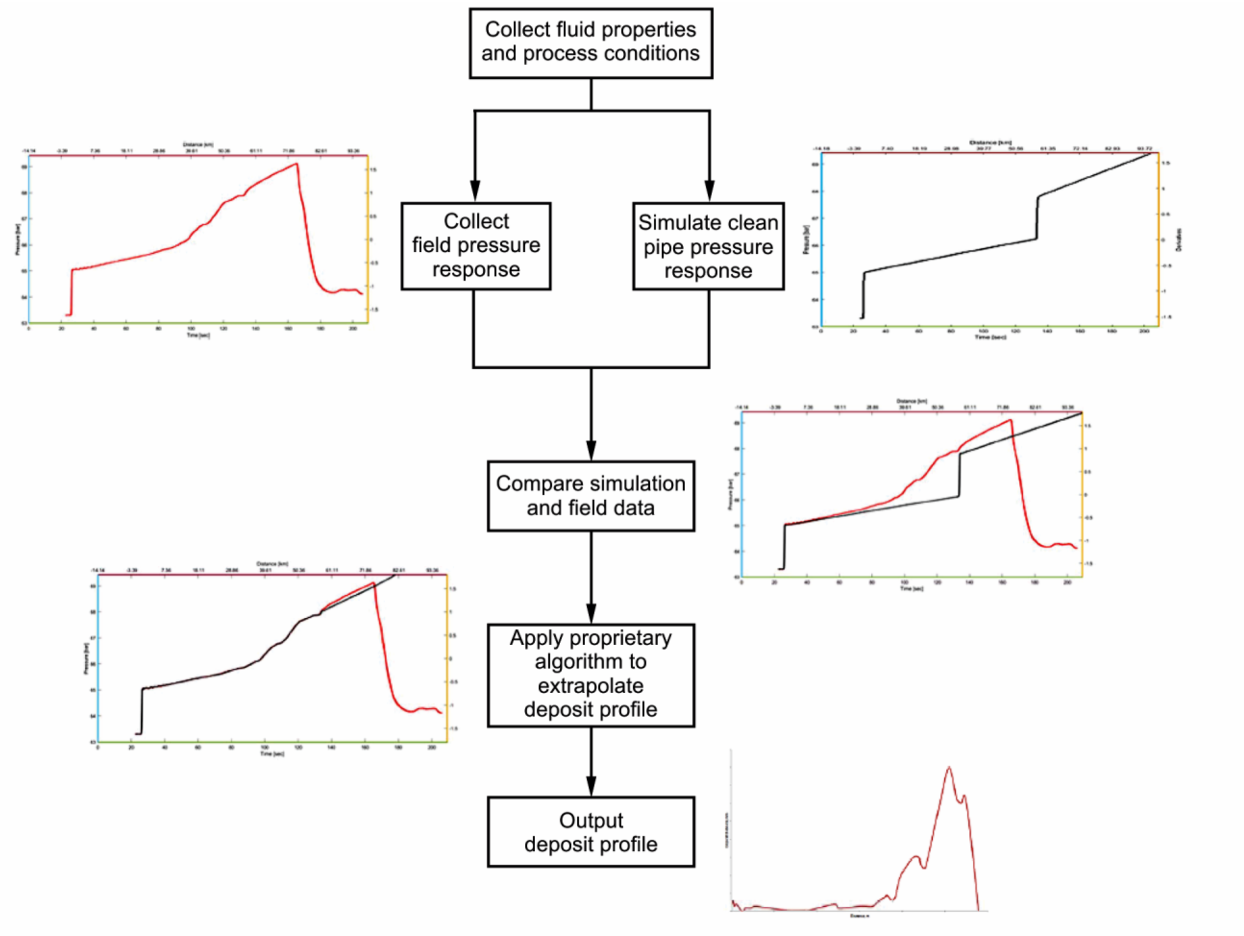

Figure 4. Debris profiling pressure wave analysis process flow

3.4. Results

During ideal conditions, results are presented with an accuracy of 1-mm deposit thickness and 100-m deposit position in the pipeline, along with the calculated total deposit volume for the pipeline, and are displayed in multiple formats—from debris thickness and hydraulic-diameter 2D graphs to 3D renders of the pipeline (Figure 5).

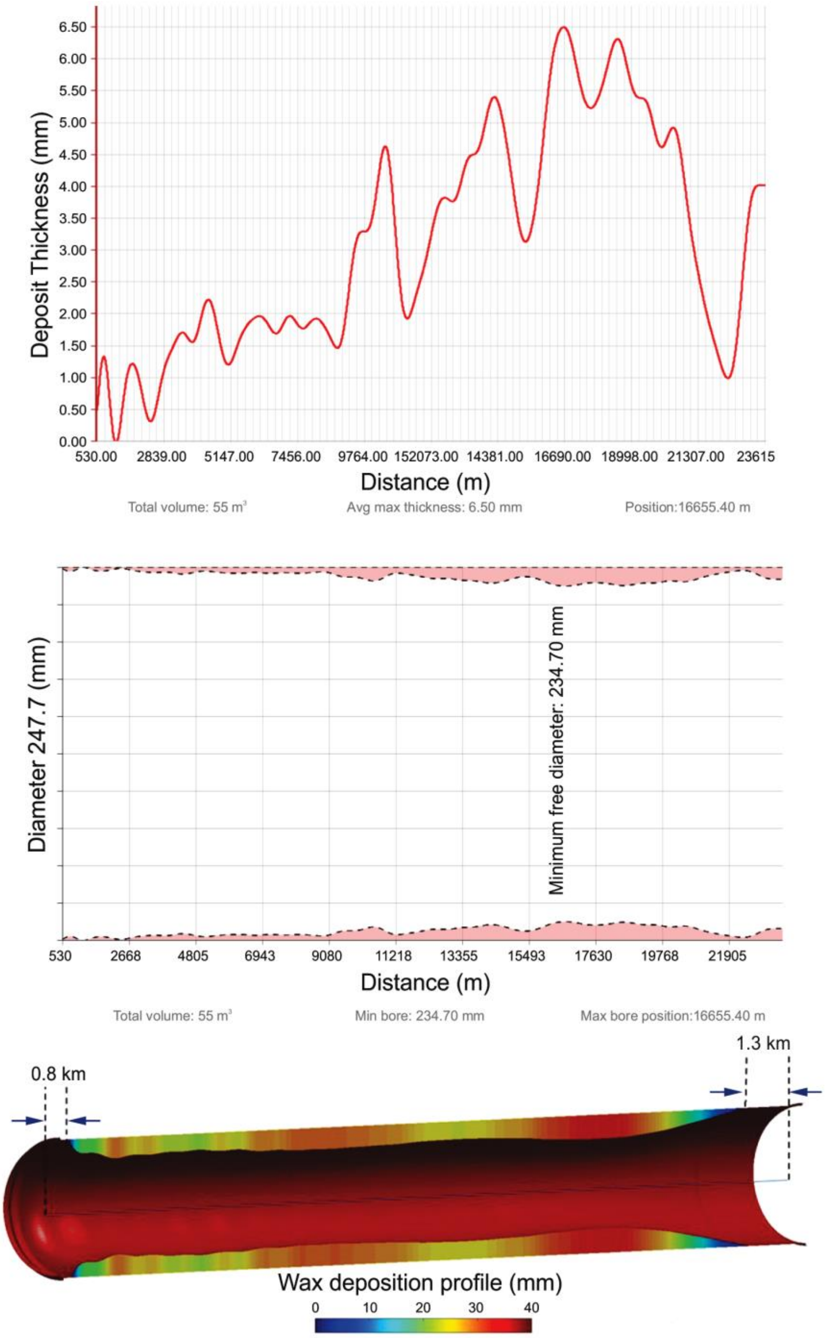

Figure 5. Debris profiling results

4. Applying Pressure Wave Analysis Technology

4.1. During Planning

Because of the pipeline's vital role for end-to-end supply, a pipeline cleaning operation is rarely undertaken without forewarning, considering that the significant amounts of planning and design of the cleaning campaign often run for months or even years. All this is often performed with either only a theoretical understanding or little to no knowledge of the internal condition of the pipeline; therefore, it is common practice to use the worst-case scenario as the point for designing the programme to limit potential risks involved. This means significant resources and costs could be expended when planning for a scenario that does not exist—whether it is because of purchasing too many pigs or chemicals, subcontracting more resources than necessary, or using more engineering and planning time than reality would dictate.

Using the pressure wave analysis technology at the beginning of the planning phase of a cleaning campaign allows pipeline operators to collect information on the pipeline without production shutdown or risking an intrusive intervention. This knowledge is then fed into the planning strategy to help ensure that the planned remediation is targeted as accurately and efficiently as possible.

With the information gained from the pressure wave analysis available (Figure 6), the pipeline operator can identify if the pipeline can be pigged, a starting point for the aggressiveness of the first pig run, the size of any chemical treatments necessary, and where they should be placed. Additionally, knowledge of the total volume of deposit in the pipeline provides guidance on how the debris removed from the pipeline should be managed and stored once it is received.

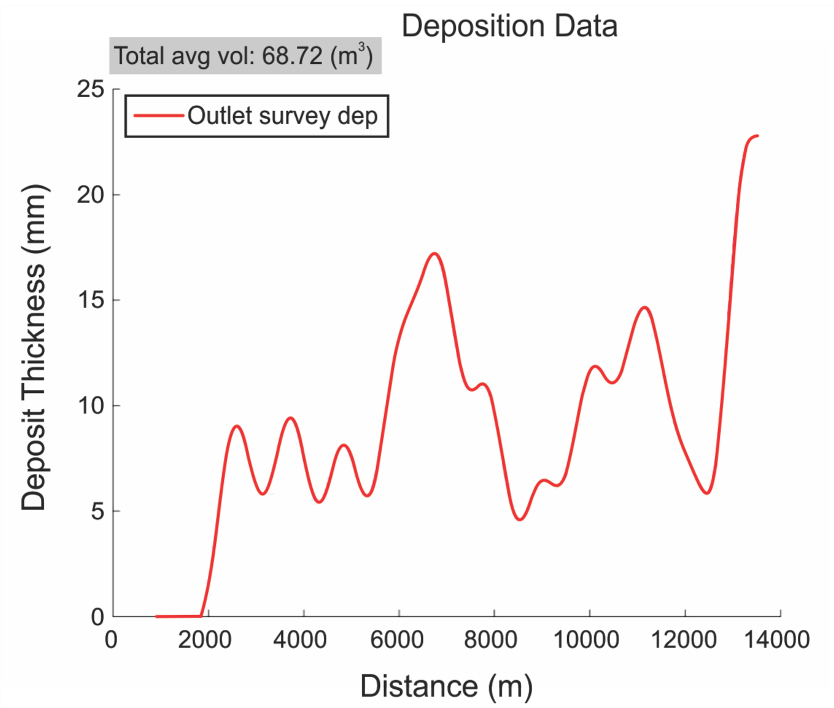

Figure 6. Example of a deposit profile

4.2. During Cleaning Operation

Once a pipeline cleaning campaign has been planned and mobilised operationally, it is best practice to monitor the progression of the campaign after each step to allow the campaign to be adapted and reassessed if it is not progressing as required or planned. Monitoring is normally performed by measuring debris volume received at the end of each pig run, evaluating its type and evolution, and assessing the condition of the received pigs. This method of monitoring has flaws that can significantly impact its effectiveness. First, consider that debris received at the pig receiver could be washed farther into the process system and could drain both during the receipt of the pig and during the preparation of the pig receiver for opening. This means there should always be doubt concerning debris volume received, which causes a conservative estimate of the progress of the cleaning campaign to minimise the potential risk. Second, a “pigging subject matter expert” who has a subjective viewpoint should assess the debris received; this viewpoint could differ between individual experts and countries.

Using the pressure wave analysis technology between pig runs, the actual remaining debris volume in the pipeline, debris volume removed from the system, and the new distribution of the deposit in the pipeline following the pig reprofile can be calculated. Because results are completely objective, a conclusive decision can be made on the efficiency of the pig and progression of the cleaning campaign. This means a standard pigging campaign, such as those run in preparation of an inline inspection (Table 2), can be tailored during operations to maximise its efficiency and reduce time and cost.

Pig No.	Pig Description
1	80% ID medium density foam pig
2	80% ID high density foam pig
3	100% ID high density foam pig
4	Foam calliper tool
5	95% ID bi-directional cleaning pig
6	100% ID bi-directional cleaning pig
7	100% ID bi-directional cleaning pig c/w wire brush
8	100% ID bi-directional cleaning pig c/w wire brush
9	100% ID bi-directional gauge pig
10	Inline inspection tool

Table 2. Example of pigging schedule

Considering the pigging programme in Table 2, it is possible that using the pressure wave analysis could reduce this pigging programme at multiple stages. During the early stage of the schedule, the technology could confirm that the pipeline bore is suitable for bi-directional pigs before all the foam pigs have been run, potentially removing the requirement for the foam calliper tool completely. Additionally, it might be possible to reduce the number of cleaning pigs to be run if the technology confirms the cleanliness of the pipeline; therefore, using pressure wave analysis could save time and resources by removing multiple pigs from the programme based on results returned. In contrast, it might be the case that the pigging programme as planned is not suitable to clean the pipeline, and results suggest that more pigs are necessary to complete the cleaning to an adequate point to run the inline inspection tool, therefore helping prevent a costly and time-consuming failed inspection.

5. Conclusion

Given the time and cost associated with planning and executing pipeline cleaning, detailed knowledge of the deposition profile and volume is important for planning a successful operation. Therefore, a valid method for identifying debris throughout an entire pipeline system both quickly (non-intrusively) without access-constraint issues or risking an intrusive intervention into the pipeline is extremely desirable.

Pipeline operators can survey pipeline debris quickly and safely using pressure wave analysis, which is repeatable and has a verified high level of accuracy, of the internal pipeline profile to provide fundamental data points to consider (i.e., is the pipeline in a piggable condition, is chemical treatment necessary, or is a more direct intervention recommended). Whichever method is necessary, knowledge gained by performing a nonintrusive survey upfront allows targeted cleaning or maintenance executed effectively, economically, and with minimal potential risk. This technique can be further implemented to track and optimise any remediation campaign as it progresses and confirms efficiency of the cleaning methodology.

6. References

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Gudmundsson, J.S., 2006, Method for determining pressure profiles in wellbores, flowlines and pipelines, and use of such method, US Patent US6993963B1.

Wallis, G.B., 1969, One-dimensional Two-phase Flow, first edition, McGraw-Hill.