University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Offshore Technology – Industrial Asset Management	Spring semester, 2014 Open / ~~Restricted access~~
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Thesis title: Optimising of pipeline maintenance using deposit profile technology	
Credits (ECTS): 30	
Key words: Pipeline maintenance Deposit profile Pigging operation	Pages: ………………… + enclosure: ………… Stavanger, ……………… Date/year

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Abstract

With an aging pipeline system, the petroleum industry is experiencing new challenges in maintaining the pipeline integrity.

In the Master's thesis, a method and technology for internal pipeline diameter detection is presented. By measuring the pressure signature during a conventional utility pigging operation, the changes in internal pipeline diameter are detected. The method is evaluated and its applicability for optimising the pipeline maintenance programme is discussed.

The first part of the thesis is an overview of the challenges that operators are facing concerning pigging operations. Various solutions are reviewed for maintaining pipeline integrity. Further is a review of current management plans with focus on inspection activities. Thesis method and technology including the theory involved is presented with relevant examples.

Two case studies at test laboratories were conducted as part of the thesis. The first case study verified the method and technology. The subsequent case study gave indications toward the method's detectability and repeatability. The result of the case studies show potential for implementation and optimisation of the pipeline maintenance programmes.

Finally, a few suggestions that might improve the technology are discussed.

Keywords: Pipeline Maintenance, Pigging Operation, Utility pigs, Conditional Monitoring, Deposit Profile

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Abbreviations:

BOP	Blow out preventer
ILI	Inline inspection
WT	Wall Thickness
OLF	The Norwegian Oil Association
UIS	University of Stavanger
DNV	Det Norske Veritas
NORSOK	Norsk sokkels konkurranseposisjon
IMS	Integrity Management System
IMP	Integrity Management process
AIM	Asset Integrity management
IM	Integrity management
BiDi	Bidirectional
DP	Differential Pressure
UT	Ultrasonic testing
ADC	Analogue to digital converter
HSE	Health, Safety and Environment
API	American Petroleum Institute

Nomenclature:

$h = Elevation\ above\ reference\ [m]$

$P = Absolute\ pressure\ [{}^{N}/_{m^2}]$

$v = velocity\ [{}^{m}/_{s}]$

$g = acceleration\ of\ gravity\ [{}^{m}/_{s^2}]$

$\lambda = \ \ darcey\ Friction\ factor\ [dimentionless]$

$L = pipeline\ lenght\ [m]$

$v = average\ fluid\ velocity\ [{}^{m}/_{s}]$

$\rho = fluid\ density\ [{}^{kg}/_{m^3}]$

$DP = Differential\ pressure\ [bar]$

$PT = Pig\ Type\ constant$

$OD = nominal\ pipeline\ diameter\ [m]$

$A = Area[m^2]$

$d = distance\ [m]$

$F = force\ [N]$

$t = time\ [s]$

$f_s\ = sampling\ rate\ \ [Hz]$

$WT = Wall\ Thickness\ [mm]$

$ID = Internal\ Dimention\ [m]$

$OD = Outer\ Diameter\ [m]$

$v_{avg} = average\ velocity\ [m/s]$

$\boldsymbol{\nu} = fluid\ kinematic\ viscosity\ [{}^{m^2}/_{s}]$

$\eta = fluid\ dynamic\ viscosity\ [{}^{kg}/_{ms}]$

$counts = number\ of\ events\ [dimentionless]$

Preface

This dissertation is original, unpublished, independent work by the author, Johannes Dahl.

I would like to thank Professor Dr. Ing. Tore Markeset at University of Stavanger. His encouragement and interest for the work has been very motivating and helpful.

Further, I would like to thank my employer KTN for supporting this project and thesis. A special thanks to Nils Arne Alvsvåg, MsC at KTN for his valuable input and discussions.

Finally, I would like to express my deepest gratitude to Sunnski and my parents for their support, guidance, proofreading, and patience throughout the work.

1. Introduction and background

1.1. The challenge of pipeline integrity

Pipeline system integrity is a key operational issue in the petroleum industry. Pipeline systems span from the production fields to the refineries and finally to the end users. Interruption in flow due to failure in pipeline systems or components such as valves, flanges, or gaskets can generate significant financial losses. However, important is health, safety and the environment (HSE) issues. The consequences of a failure in pipeline integrity could be disastrous. A recent example is the Macondo incident of the BP Deepwater Horizon accident in the Gulf of Mexico. A gas leak and subsequent explosion in combination with component failure, ultimately rendering the emergency blow out preventer (BOP) to seal off the well. The following fire burned for 36 hours before the drilling rig sank. An estimated 3.26 million barrels of oil were released and eleven operators died. Subsequent response activity costs have exceeded $14 billion (bp.com, 2013).

Pipeline maintenance management is imperative in preserving pipeline integrity. Effective pipeline maintenance management must determine the maintenance objective, strategies, and the responsibilities. The implementation of these through an organized work process is a crucial factor in order to anticipate and prevent pipeline system failure. Failure compromises both company assets and the environment. Pipeline operators' maintenance management is normally based on regulations and industry standards established by national and international regulators. NORSOK is the applied Norwegian industry standard developed, updated, and regulated in cooperation by and for the petroleum industry.

Deteriorating pipelines provide a substantial challenge to the pipeline integrity. The deterioration may affect the pipeline both internally and externally. It is therefore important for the operators to assess the pipeline conditions regularly. Pipeline operators apply both internal and external assessment methods in order to establish the pipeline condition. External assessment methods are often inconvenient, costly and time consuming as the vast majority of pipelines are either buried or located subsea (Tiratsoo, 1992; Russell et al., 2005). However, by accessing the bore of the pipeline, internal and external pipeline assessment data are obtainable. The feedback of conditional assessment data into the pipeline integrity strategy can potentially yield early detection and identification of developing pipeline threats.

Internal pipeline condition is also critical with concern to flow assurance and the overall pipeline integrity. The term "pig" is used to describe a tool that travels through a pipeline during a pigging operation. The name originates from the first applied tools that made a characteristic squealing noise when driven in the pipeline, hence the name pig (Tiratsoo, 1992).

Applying pigging operations is a preferred means in maintaining the pipeline integrity. Various difference types of pigs are used for ensuring flow assurance, condition monitoring as well as pipeline specific tasks such as removal of unwanted objects and impurities in the pipeline.

The traditional pigging processes employ utility pigs as tools for preparing the pipeline for a subsequent intelligent inline inspection (ILI). The assessment data is dependent on the analysis and interpretation of the recovered data collected during the ILI operation. The typical ILI is a train-based configuration containing a wide array of miscellaneous modules. Each module is designed with a specified assigned function. The ILI train complies with the operators' specifications in providing particular conditional data from the pipeline.

While intelligent inspection pigs have been under a continuous technological development since they were introduced into the marked in the late 1950s (Tiratsoo, 1992), conventional utility pigs are however to some extent unrecognized as a source for obtaining valuable information. Furthermore, when a utility pig is used as a carrier for an ILI tool, the ILI contractors tend to deem the added carrier pig as a potential problem. Russell et al. challenges this notion, and claims that utility pigs could be considered as sensors (2005) by applying basic physics and state-of-the-art technology.

Utility pigs may thus be potential candidates in providing operators with useful conditional assessment information, which is a main question discussed in the thesis.

1.2. Problem formulation of the thesis

1.2.1. Challenges in current pigging operations

Conventional utility pigs and ILI pigs are the two main categories of pipeline pigging tools. The former is often applied to prepare a pipeline for a pigging operation by the latter. The pipeline cleanness obtained by a utility pig is a precondition necessary to acquire the desired subsequent assessment results from the ILI pigs. To collect data of satisfying quality the ILI pigs' configuration, specification and pigging purpose dictate the degree of preconditioning requirements regarding the pipeline cleanness. The ILI tool thus highlights the importance of utility pigging in pipeline maintenance.

Pipeline operators' conventional pigging strategy is often due bona fides, and the first evincing signs of an inadequate maintenance strategy appear after the completion of an ILI pigging operation (Tiratsoo, 1992). Large amounts of unusable data from the ILI pig will often be the outcome when lacking or unfulfilling the set requirements regarding the precondition of pipeline cleanness. The analysis outcome of good quality data acquired by the ILI forms a solid base in the evaluation of the pipeline maintenance strategy. The crucial necessity is that ILI data is of good quality, trustworthy and accurate. Comparing the complexity, resource requirements, and the associated risks of the two pigging categories, it is evident that conventional pigging and its utility pigs have an unexplored potential.

One of these potential paths could be in connection with the information obtained from conventional pigging and the utility pigs. The common practice is often an informal after- run-assessment of the utility pig itself. The operators' assessment is a condition evaluation of the pig employed and the quantity of debris accumulated in the pig receiver (Tiratsoo, 1992). The evaluation process after a utility pig run depends on the initial pig configuration and the purpose for pigging. Data collected should be analysed and stored properly, yet this is often not the case. The omission of such data from the utility pig performance and the lack of regular feedback to the pig contractor set limitations on further improvements of the utility pigs.

Some coherent conclusions may be observed based on the after-run-assessment of the utility pigging operation. This may provide some information towards a certain condition criteria within the pipeline. The after-run-assessment utilise this when recognizable indications of a specific pipeline condition are observed, e.g., deposits in the pig-receiver means there are or were deposits in the pipeline. Another example of a coherent conclusion would be, a utility pig is launched into the pipeline at a given location and arrives at the pig-receiver. The evaluation found no damages on the utility pig after arrival. One logical conclusion from this is that the pipeline, from the launcher to the receiver, does not contain any internal full-bore blockages. This coherent conclusion may seem trivial but it still represents one of few sources of information from the utility pigging operation.

According to Tiratsoo a main question prevails "[…] what is effective pigging? At this moment, no one knows. There are lots of theories, but few, if any FACTS." (1992,p.450). Tiratsoo's statement is to some extent valid even today. To establish whether a pigging operation is in fact efficient certain acceptance levels and criteria must be predetermined. Organized parameters regarding the operational objective, the pipeline and pig specifications enable the compilation of a register that represents a key element in the decision making process. The process outcome specifies the criteria and tolerances to assert the efficiency of a pigging operation. Over the years, many different methods and approaches have been tried attempting to gain valuable information concerning the pigging operation and its efficiency.

1.2.2. Current method and approaches

Many different methods have been developed to both detect and remove internal pipeline deposits, considering the challenge deposits are in maintaining pipeline integrity. The overall research has shown that there are several problems to address. A significant amount of research has been preform on developing mathematical modelling of wax behaviour. These are theoretical approaches and can either be modelling of paraffin wax in oil pipelines (Siljuberg, 2012; Rosvold, 2008), modelling of wax thickness within the pipeline (Botne, 2012), or the structure of wax deposit in pipelines (Kjøraas, 2013a).

A practical approach for detecting deposits is done by using pressure pulse or pressure wave technology. This technology uses the pipeline medium to create a pressure pulse/wave that traverse the length of the pipeline. The data recorded and the subsequent analysis of the transmission, enable estimations of potential reduction in average internal pipeline diameter, meaning the average thickness of the deposit build up. The physical phenomenon applied by this technology utilises the water hammer and line packing effects. The water hammer is triggered by closing a valve that stops the pipeline flow, which then generates the effect (Falk, 1999; Pierre, 2009).

Some research has looked into development and modification of utility pigs. The aim is to obtain more information towards increasing efficiency of the pigging operation. Cleaning pig has also been temporarily converted into a smart pig by equipping the pigs with different sensors for measuring conditional parameters within the pipeline such as pressure and temperature (Nicholson, 2004). Another smart pig modification researched, was to acquiring vibration data emitted by the cleaning pig during the pigging operation, which is a relative new approach. The approach is to inspect the corrosion on the internal wall by differencing the recorded pig vibrations. An increase in surface roughness caused by corrosion will correlate to the amount of energy for pig vibration. The on-board vibration sensors record the data continuously for future analysis. Indications from trials conclude that a fingerprint for corrosion will not be valid in all situations. A baseline for each pipeline, against which changes may be monitored is recommended by Russell et al. (2005).

The last pigging approach mentioned is the development of a model of the pig motion in the pipeline. The models goal is to prediction the pig motions within the pipelines. The model is based on analytical hydrodynamic theory. The considered models are for incompressible, steady state flow. The research refers to the fact that most information is knowledge based and gained from field experience and argues the need for a scientific based approach to pigging operations. Moreover, it concludes that such information as run time predictions will aid engineers in optimising the pigging operations (Azevedo et al., 1996). Modelling of pig operation in natural gas line is also been substantial researched (Esmaeilzadeh et al., 2006), but this is outside the thesis scope and will not be further reviewed.

1.3. Objectives of the thesis

1.3.1. Main objectives

The main purpose of the thesis may be expressed by the following success criteria or hypothesis:

"***Pigging maintenance programmes will be optimised based on the assessment of data obtained from a sensor mounted on the pig launcher recording emission from a conventional utility pig during a pigging operation***".

The primary object is to introduce and demonstrate a method and technology for use during conventional pipeline pigging that could acquire information regarding the pipeline condition.

Considering the outcome of the first objective, the following objective is to review, evaluate and discussion of the possibility for pipeline maintenance optimisations in the integrity management process.

1.3.2. Sub - objectives

One sub objective is to determine and analyse the applicability of the methodology used in the presented technology. The methodology used needs to be recognised by the petroleum industry. The mathematical models chosen need to incorporate all the relevant parameters necessary for a correct representation.

Another sub-objective regards the instrumentation required. The instrumentation specification needs to be established and be qualified for their appointed task. Different requirements are in place depending on instrumentation location. Rules and regulations may vary depending on the locations; onshore, offshore or at test facilities.

Finally, an important sub-objective is to demonstrate the method at test facilities. Several test facilities were evaluated in order to find the right location for the evaluation and demonstration of the method. Two facilities were chosen and these are used in the thesis work.

1.4. Thesis outline

The outline of the thesis is illustrated in Figure 1 and the main workflow between chapters in also shown.

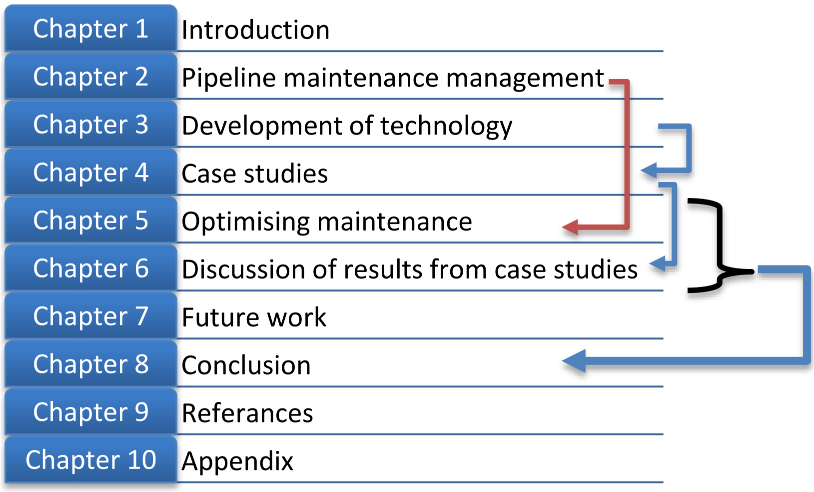

Figure 1 Work flow in thesis

The introduction and project background is presented in chapter one. This chapter also includes the problem formulation and objectives. Limitations, delimitation, and a review of current methods are the final part of this chapter. Chapter 2 reviews the integrity management process focusing on pipeline maintenance. Maintaining integrity during operation and general pigging operations are reviewed. Chapter 3 present the new method, the theory, and the methodology. Both case studies are presented, evaluated, and discussed in Chapter 4. The optimization of maintenance programs using the presented methods are reviewed and discussed in chapter 5. Further discussions concerning the case studies are summarised in Chapter 6. Chapter 7 presents some suggests and options for further development of the method and technology this is found in, Future work. Chapter 8 is the conclusion and it is the final chapter prior to the references and appendix.

1.5. Literature, theory and methodology

A cooperation by a wide array of participants from the Norwegian petroleum industry has established the NORSOK standards. The Norwegian Oil Association (OLF) has supported the development of these standards. The standards aim to create a common foundation for the industry. The standards are utilised as regulative reference documents for the authorities. Therefore, the NORSOK standards are referred to and are used throughout the thesis. In addition to the NORSOK, the DNV standards and recommended practices provide an important source. One particular important document is the DNV-RP-F116 (Veritas, 2001).

Useful information uses is available are OnePetro.org, which contains many petroleum related articles. Other online article databases, journals, and academic literature from universities worldwide have also been used.

Furthermore, important source documents for maintenance theory and methods are found in course compendium MOM 400 and MOM 460, UiS. Amongst the book literature studied and used, the most significant are Tiratsoo (1992), Cordell et al. (2003), Guo et al. (2014) and Menon (2004). The above literatures represent the main source for establishing the theory and method applied in this thesis.

Finally, the authors working experiences from six years of pipeline pigging operations represents a knowledge base, which has been referred to where appropriate.

1.6. Research limitations and delimitations

The focus of the thesis is on methods that directly or indirectly deal with internal pipeline conditions. Both newly published and established methods have been reviewed. The reviewed methods have been evaluated to find their contribution towards pipeline maintenance and pipeline integrity.

The new method and technology presented in the thesis has not been described in the literature researched by the author. Limitations on time, literature access, and professional secrecy means that the author cannot exclude that the method presented here is untried or previously evaluated by other researchers or companies.

The hypothesis is based on experience from field operations and Christian Michelsen Research has reviewed the theoretical foundation on pressure transmission in pipelines. These theories are well established and accepted in the industry. They are also applied in many different methods, techniques, and applications within the industry.

The overall scope is set to present the method and as far as possible evaluate and verify it under laboratory condition. Assumptions and limitations are present in both the method calculations and to some extent when evaluating and analysing the case studies. If assumptions or limitations are made or known, they will be mentioned. There may be parameters that are disregarded for in the case studies, due to their insignificancy. However, they may appear to be of utmost importance when utilising the method under operational circumstances. Because of this, the results presented in this thesis, may not be directly transferred to an actual operational situation. This challenge is further reviewed in chapter 0.

2. Pipeline maintenance management

Pipeline maintenance management is an integrated part of the overall Integrity Management System (IMS). The operators are required to establish and maintain an IMS that complies with all current standards and regulations. The IMS overall scope is to ensure pipeline system integrity during the entire pipeline lifecycle. To achieve this goal, a series of minimum requirements are determined through standards and recommended practices. The Norwegian governing standards are the DNV-OS-F101 (Veritas, 2009).

The core of the IMS is the Integrity Management Process (IMP), Figure 2. The elements surrounding the IMP serve several functions, and these elements have a supporting role. Some of the support functions are amongst other, company policy, organization, audits, reporting, and communication. The IMP and outer layer complete the IMS and are illustrated in Figure 2. The thesis focus is primarily on internal pipeline maintenance as part of the IMP. Comprehend and understanding pipeline maintenance is important in this work and specifically the contribution of maintenance in the IMP.

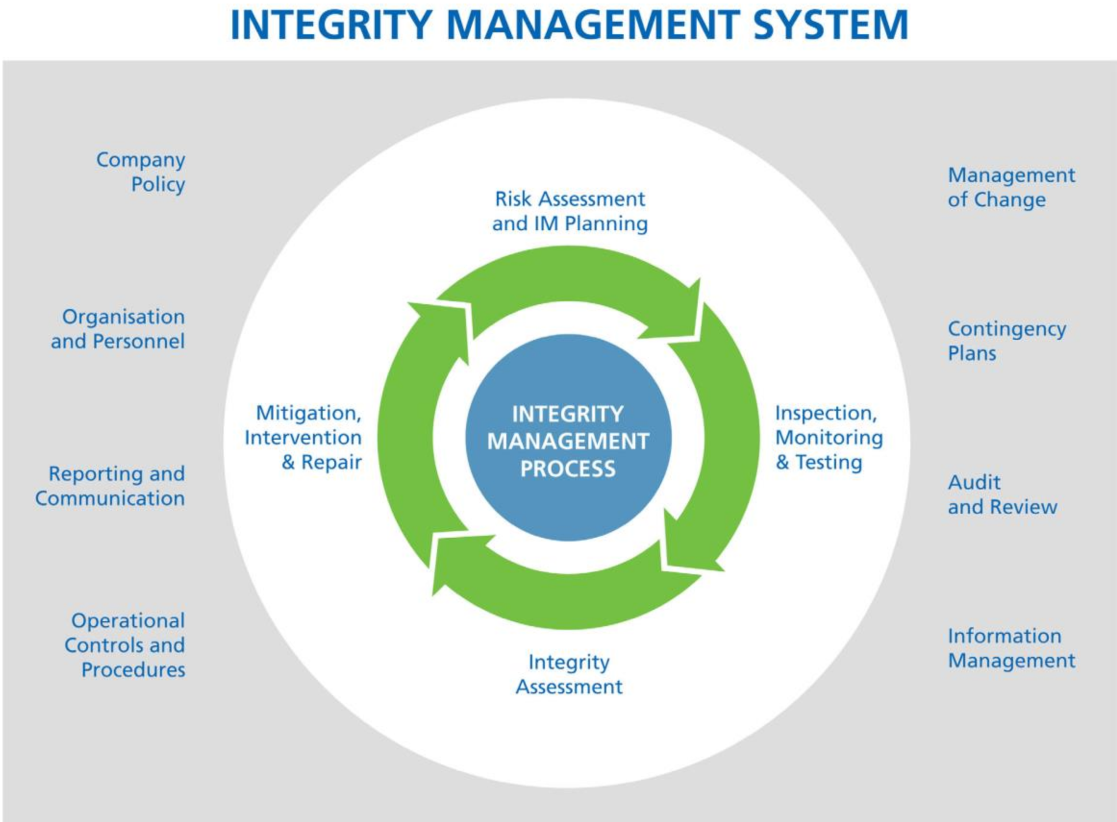

Figure 2 IMS. The white section is the Integrity Management Process (Veritas, 2009,p.10)

2.1. Pipeline Integrity

Pipeline integrity is involved throughout all phases of the pipeline lifecycle. From the first pipeline concept to the day of decommissioning, integrity management is involved. The process illustrated in Figure 3 is recognised and described in both the Integrity Management System (Veritas, 2009) and the Asset Integrity Management (AIM) (Jong et al., 2009; Markeset and Ratnayake, 2012).

Figure 3 Process from concept to operation as presented in (Veritas, 2009)

The integrity of the pipeline is established and identified during the concept and design phase (Veritas, 2009). It is important to note that future maintenance programmes depend on decisions taken and requirements set in the first phases of bringing the pipeline system into being. "[…] maintenance needs of systems, are more or less decided during the design and manufacturing phase" (Markeset, 2003,p.377). The initiation of maintenance programmes' configuration and manning requirements are also initiated during the early phases (NORSOK, 2011).

Early decisions made during the conceptual phases regarding pig launcher design may have impact on future operability and operating costs. If the pig launcher is installed subsea, investment costs can be reduced, but pigging operations will be quite comprehensive and costly. This will influence the pigging frequency in the maintenance programme.

Prior to the operational phase, the initial maintenance programmes need to be implemented into the IMS and transferred to the pipeline operator. This involves the transfer of vital data, documentations, calibrations, procedures, and other information important for maintenance and maintaining the overall pipeline integrity during the operation phase. This is the transfer integrity and overlaps both the construction and the start of the operational phase. The complexity and risks of the pipeline system along with the operators experience dictate the effort needed to ensure a smooth transition (Veritas, 2009).

2.1.1. Threats and failures

There are a number of threats that can influence and eventually compromise pipeline integrity. The process from threat to pipeline failure is illustrated in Figure 4. The understanding of how components interrelate in a process and influence each other is important. Changing a parameter in one stage of the process, will in course of the process influence the overall behaviour. Understanding and considering all stages in the process, can reduce the probability of creating an unforeseen and unwanted incident at a subsequent stage (Veritas, 2009).

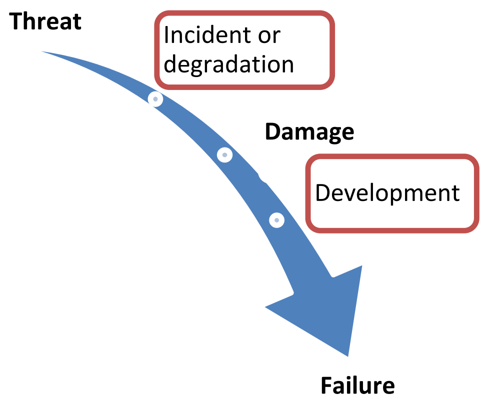

Figure 4 the chain of events from threats to failure

A chain of events that could lead to failure is an incorrect operational threat. An example of an operational threat could be that a production procedure concerning the production temperature and pressures was not implemented correctly. This could leads to deposits build up and develop into internal corrosion (i.e. metal loss), and over time, this could eventually lead to a failure (i.e. loss of containment) (Veritas, 2009).

2.2. Pipeline maintenance in the integrity management process

The Integrity Management Process (IMP) can be compared to the integrity process presented in Figure 3. This meaning that the four involved stages of the IMP can be identified in this integrity process. Figure 2 shows the IMP and the four involved stages (white circle).

In the contexts of the IMP, all three stages except the *Risk Assessment and IM planning* are involved in the operational phase. *Risk Assessment and IM planning* describes the long-term strategies and establishment of the initial maintenance programmes. In addition, it sets guidelines concerning annual and periodic updates. Finally, requirements such as frequency of pigging operations and risk assessments are made based on the pipeline and its configuration. This group is reviewed in Chapter 0. The focus of this chapter is on maintenance within the *Inspection, Monitoring and Testing.*

2.3. Inspection, monitoring and testing

The pipeline operational phase scope is to maintain the pipeline integrity by preforming integrity control - and improvement activities.

Inspection and monitoring are defined as control activities. A detailed plan for these control activities is prepared using the framework developed by the *Risk Assessment and IM-Planning*. In addition to the framework, it sets requirements concerning when and why to update. The inspection and monitoring programme normally covers and initiates all pipeline maintenance activities. Pipeline maintenance is further divided in to several sections depending on the threats and criteria set in the early phases. The two main groups are internal and external pipeline inspection. External pipeline inspection is often denoted as surveys, and as previously stated, this is not covered in the thesis scope (Veritas, 2009). The common understanding is that internal inspection is often related to the use of ILI, and that internal pipeline maintenance covers the use of utility pigs.

Monitoring is the indirect approach in obtaining the state of a component (Veritas, 2009). This is done by collection process data that can give indication toward the state of a component. Monitoring activities can be done either on- or off-line. Scheduled sampling and subsequent offsite analysis is the definition of off-line monitoring. Sampling the production and sending it for analysis is an example of off-line monitoring. On the contrary, online monitoring would involve continuous or real-time data collection of a parameter in order to acquire information about a specific condition.

2.3.1. Pigging operation

Pigging operations are a part of the day-to-day activities in maintaining the pipeline integrity. The maintenance activities are scheduled and planned prior to the operation phase. If for any reason an unacceptable situation should arise during the normal scheduled operation, the activities shall stop. A subsequent report, review and evaluation should result in the appropriated response is taken to further maintain or if necessary restore the pipeline integrity.

A field example from the authors experience and as documented by Hester (2012) and Kobbeltvedt (2009) is found in the North Sea at ConocoPhillips' Norpipe. The Norpipe is a 357-kilometer long crude oil pipeline between Ekofisk and Teesside. The pipeline has been in operation since 1974 and has regularly had internal inspections undertaken the last 25 years. Corrosion growth in the pipeline became a potential failure mode in 2007 and the pipeline integrity was threatened. The situation became unacceptable and the operator initiated a process of reducing the possibility that the anomaly found would develop into a failure. As result of a risk-assessment, a large-scale pigging program was established, the programme stages is illustrated in Figure 5. New development of cleaning pigs, chemicals and inspection equipment was undertaken to get the corrosion growth under control. The general pig-cleaning program consisted of five different cleaning pigs ranging from light foam pigs to aggressive cleaning tools. Each designed for a specific function from verification of pig ability to removal of hard scale. Intelligent ILI pigs mapped the severity of the corrosion in order to assess the damage and form the bases to assure pipeline integrity. Continuous treatment with chemicals and monitoring of samples were other actions taken. The precautionary work managed to control the corrosion rate and prevent the anomaly from developing further into a pipeline failure.

Further usage of Inline Inspection (ILI) pig each designed to provide certain information regarding the pipeline condition. The information might range from corrosion, wall thickness, cracks, and 3D geometry. On a general note, the advantage of using ILI tools in a pipeline maintenance strategy is indisputable. This is reflected in large-scale demand for state of the art ILI tools with different technologies.

In contrast to the demand for state-of-the-art ILI, some operators have been using the same cleaning BiDi pig for decades (Tiratsoo, 1992). Yet, the majority of the industry has realised the importance of pigging. Along with the aging of the pipeline systems, the amount of specialized tool has increase concerning purpose made ILI tools and a large array of different utility pig design. This is to meet the increasing needs of the pipelines operators.

Conventional utility pigs

Utility pigs are a collective term for pigs that perform internal pipeline cleaning, separation and dewatering. Cleaning, sealing, foam, and spherical pigs are sub-categories.

A pig can either be uni- or bi-directional (BiDi) meaning the prior is not capable of moving in both directions in the pipeline. Being able to run the pig in both directions may be necessary for some operations. BiDi pigs are often used if there is a possibility the pig can stall due to deposit build up in front of the pig. Flow reversal is one option in getting the pig loose but the pig had to be bidirectional (BiDi).

General build of a cleaning BiDi pig consist of a body and polyurethane disks and there are many options such as multi diameter pipelines and different bypass rate. A friction pig is a cleaning pig with several disks and often equipped with a harder grade of the polyurethane. The purpose of this setup is to have a higher differential pressure (DP) over the pig before it starts to move. Applications of such pigs may be to hold a water column or have an increased friction towards the internal wall.

Foam pigs are often used when the configuration of the pipeline is unknown or when the isometric pipeline drawings are inconclusive. A foam pig is soft and is able to pass large features protruding the pipeline bore. A foam pig can be configured to dissolve into the pipeline medium after a given amount of time. The time it takes to dissolves is usually longer that the planned pigging operation. An advantage is that it significantly reduces the probability of a “stuck” pig.

As stated, each utility pig should to be designed for its specific function. Reviewing the cleaning program developed in the ConocoPhillips example in section 2.3.1 gives insight in the variety and the necessity of utility pigs in maintaining pipeline integrity. The exact design specifications and pigging schedules cannot be disclosed due to confidentiality clauses. The following is a general overview concerning the utility pigs used in the campaign. The pigging operations developed can be divided into five stages each with a specific objective and a corresponding utility pig.

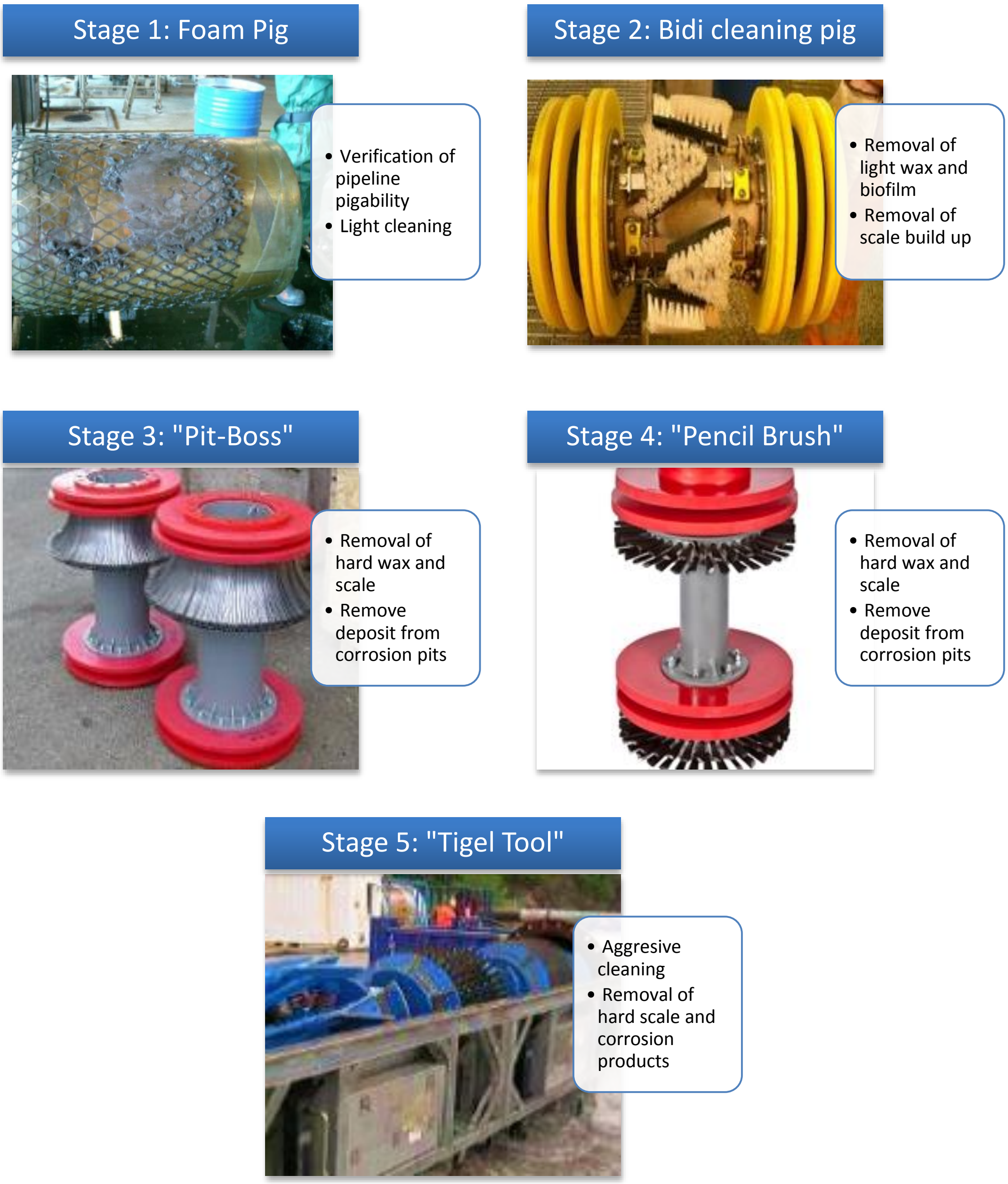

Figure 5 Overview of cleaning program at Ekofisk

Note: Pictures in stage 1,2 and 5 are from Kobbeltvedt (2009) and pictures in stage 3 and 4 are from tdwilliamson.com (2014)

3. Development of deposit profiling technology

The development process used for the deposit profiling technology covers the system specifications, requirements, methodology, evaluation, and assessment.

A general system operation is illustrated in Figure 6. The figure shows a schematic diagram of the system during a pigging operation. The figure illustrates a utility pig that is driven through the pipeline by the medium flow. The utility pig in the illustration is a BiDi pig with polyurethane disks. The pressure waves are emitted when the pig moves, these waves traverse in the opposite direction of the flow that subsequently moves the pig. When the pressure waves reach the pressure sensor, the sensor membrane reacts and a corresponding signal is sent to the logging device. In Figure 6 the collected data is analysed and plotted onto the data screen.

The main system function is to detect and locate internal diameter changes in a pipeline during a conventional pigging operation. A sub function is to record several pigging operations and by comparison generate a pipeline deposit profile.

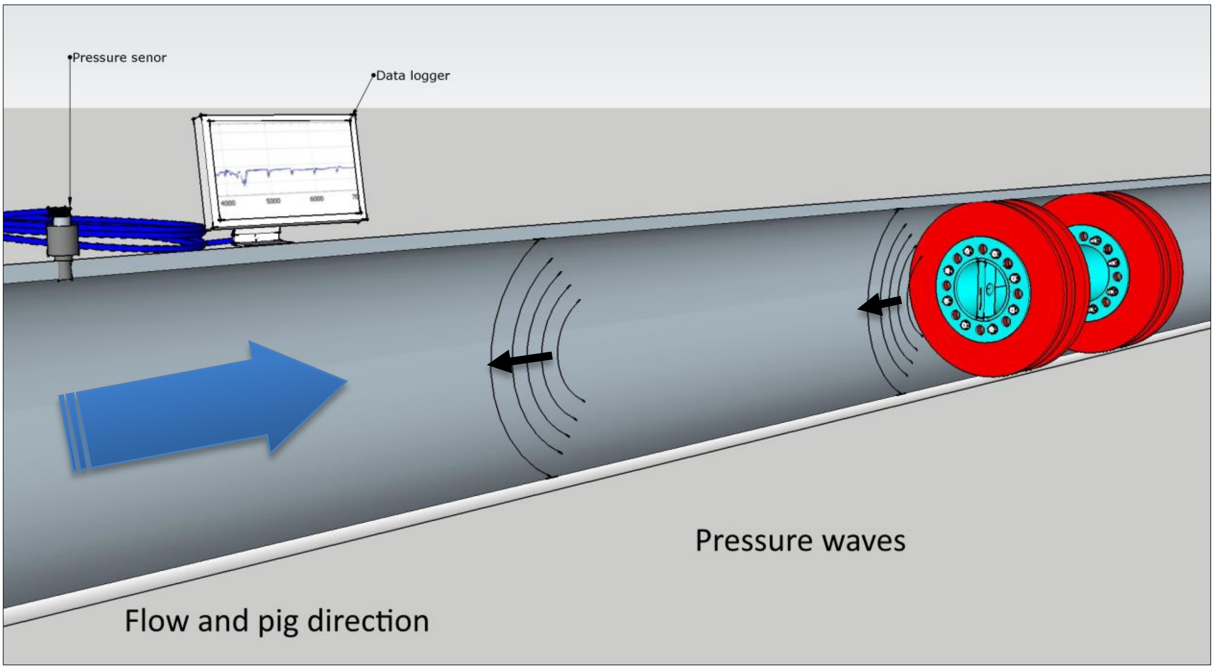

Figure 6 Schematic diagram of the Deposit Profiling technology

3.1. Theory introduction

A pigging operation involves many physical phenomena and corresponding theories. There have been substantial research within the industry in order to gain valuable information from these phenomena. The most significant theories involved in a pigging operation relevant for this thesis are:

- Pipeline fluid flow theory
- Pig behaviour theory

In section 3.1.1 below, the fluid flow characteristics within the pipeline are reviewed. Further, the effect the pigging operation has on the pipeline fluid flow characteristic is evaluated.

Several factors need to be evaluated in order to find the theory foundation concerning the pig behaviour. A general review and description of the most important theories and their influence are found in section 3.1.2.

3.1.1. Pipeline fluid flow theory

Conservation of continuity is the fundamental concepts of fluid dynamic. A basic understanding is required in order to correctly evaluate and analyse the data acquired during the case studies. The governing equation is the continuity equation. It states that the total amount of fluid passing through any section of a pipe is fixed.

$$\rho * A * v = constant$$

Equation 1 Continuity equation

The density, velocity and area of cross section of pipe are respectively, p, v, A. Adding the assumption that liquids generally are considered being incompressible gives an insignificant change in density and thus $\rho_1 = \rho_2$. Equation 1 is rewritten to:

$$A_1 * v_1 = A_2 * v_2$$

Equation 2 Continuity equation for an incompressible liquid

This meaning that the area of cross section of pipe A and the velocity v is inverse proportional dimensions (Menon, 2004).

$$v_2 = \frac{A_1 * v_1}{A_2}$$

Equation 3 Continuity equation for an incompressible liquid solved for v_2

Figure 7 illustrates a horizontal pipeline where the change is a reduction in the internal diameter. This is similar to a feature that was present during the first case study. In the following examples, the data obtained from that case study will be used. The reason for this is to increase the relevancy of the examples presented.

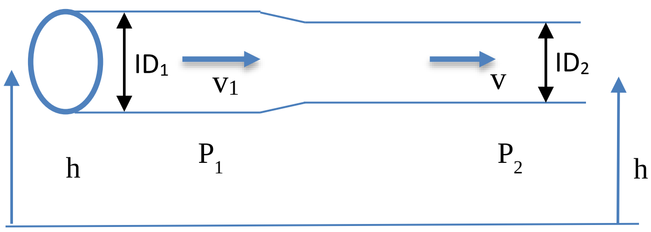

Figure 7 illustration of flow properties in a pipeline

The following equation is a well-known equation for calculating the area of a circle, it is shown to simplify the summarisation done below.

$$A = \frac{\pi * ID^2}{4}$$

Equation 4 Calculation of area

When summarising the equations, the following is obtained. From Equation 3 the reduction in pipeline diameter $ID_1 > ID_2$ results in a higher velocity within the reduced pipe segment $V_1 < V_2$.

The next step is the Bernoulli's equation that embodies the basic principle of conservation of energy appropriate for flowing fluids, with the following equation:

$$P_1 + \frac{1}{2}\rho_1 v_1{}^2 + \rho_1 g h_1 = P_2 + \frac{1}{2}\rho_2 v_2{}^2 + \rho_2 g h_2$$

Equation 5 Bernoulli's equation

where:

$h = Elevation\ above\ reference\ [m]$

$P = Absolute\ pressure\ [{}^{N}/_{m^2}]$

$v = Velocity\ [{}^{m}/_{s}]$

$\rho = Fluid\ density\ [kg/m^3]$

$g = Acceleration\ of\ gravity\ [{}^{m}/_{s^2}]$

By reviewing each segment of the equation, the following is found (Menon, 2004).

$P = Statci\ pressure\ or\ Pressure\ Energy$

$\frac{1}{2}Pv^2 = Kinetic\ Energy$

$\rho gh = Potential\ Energy$

To further expand on the illustration in

Figure 7, the Bernoulli's equation can yield further information on the parameters and the relationship between them. The next step presented here is to calculate the pressure and flow velocity in a pipeline with change in ID.

Further solving for the pressure in Equation 5, an ideal frictionless state and a horizontal pipeline, $h_1 = h_2$, is assumed.

$$P_2 = P_1 + \frac{1}{2}\rho_1 v_1{}^2 - \frac{1}{2}\rho_2 v_2{}^2$$

Equation 6 Solving for P_2 assuming horizontal pipeline

The result is $P_1 > P_2$ given the assumptions above. This means that by reducing the internal diameter from ID_1 to ID_2, the fluid velocity will increase, $V_1 < V_2$ and the internal pressure will decrease, $P_1 > P_2$.

In the Bergen case study, one of the pipe spool in the test loop had a larger ID than the subsequent pipe spool. To get an understanding of the theory the actual dimension from the case study are applied below.

The case study values are found in Chapter 0, inserted into Equation 6, as illustrated in

Figure 7. The test loop in Bergen is horizontal, $h_1 = h_2$ and the fluid is fresh water at 5 °C.

$\rho_2 = \rho_1 = 1000\ Kg/m^3$

$v_1 = 0.117\ {}^{m}/_{s}, \qquad ID_1 = \ 0.3814\ m, \qquad ID_2 = \ 0.3714\ m,$

$P_1 = \ 2.7bar = 2.7 * 10^5 N/m^2$

Velocity v_2 can be solved from Equation 3.

$$v_2 = \frac{A_1 * v_1}{A_2} = \frac{(\frac{\pi \, {ID_1}^2}{4}) * v_1}{\frac{\pi \, {ID_2}^2}{4}} = \frac{{ID_1}^2 * v_1}{{ID_2}^2} = \frac{(0.3814m)^2 * 0.117 \, {}^{m}/_{s}}{(0.3714 \, m)^2} = 0.123 \, {}^{m}/_{s}$$

Further, P_2 can be solved from Equation 6.

$$P_2 = P_1 + \tfrac{1}{2}\rho_1 {v_1}^2 - \tfrac{1}{2}\rho_2 {v_2}^2$$
$$= 2.7 * 10^5 \tfrac{N}{m^2} + \tfrac{1}{2} * 1000 \, {}^{Kg}/_{m^3} * (0.119 \, {}^{m}/_{s})^2 - \tfrac{1}{2} * 1000 \, {}^{Kg}/_{m^3} * (0.123 \, {}^{m}/_{s})^2$$
$$= 2699 \frac{N}{m^2} \approx \ 2.7bar$$

The calculation above shows that a reduction in ID will decrease the pressure insignificant when using the data from the case study in Bergen, and is therefore disregarded.

When adapting this to an actual pipeline in operation, the assumption made will not be adequate due to other physical phenomena.

The next phenomenon that needs to be addressed is flow regime. The flow regime in a pipeline is important in relation to the friction factor and the pipe wall roughness. The flow regime in comparison to the Reynolds number (Re) is:

$Laminar\ flow: Re < 2000$
$Critical\ flow: Re > 2000\ and\ Re < 4000$
$Turbulant\ flow: Re > 4000$

Further information on the flow regimes is available in Menon (2004).

All flows can be categorised by the dimensionless Reynolds number. The Reynolds number equation enables the establishment of the present flow regime in the pipeline. The behaviour of the flow depends on the flow rate, internal diameter, the viscosity, and density of the liquid. These parameters allow the calculation of Reynolds number.

$$Re = \frac{vID}{\boldsymbol{\nu}} \text{ or } Re = \frac{\rho v ID}{\eta}$$

Equation 7 Reynolds number

$v = average\ flow\ rate\ velocity\ [{}^{m}/_{s}]$
$ID = internal\ pipeline\ dimention\ [m]$
$\boldsymbol{\nu} = Fluid\ kinematic\ viscosity\ [{}^{m^2}/_{s}]$
$\eta = Fluid\ dynamic\ viscosity\ [{}^{kg}/_{ms}]$

By comparing the recommended pigging velocity with the fluid velocity, it is possible to get an overview of what to expect within the flow regime depending on pipeline dimension. There are significant differences with regards to what kind of flow regime there is in the pipeline. The following table is made by the author and this made to show the general recommended pig velocities compared to typical pipeline diameter sizes. The table present the calculated RE for the pipelines sizes in question. An assumption made is that the pig velocity is equal to the fluid velocity.

Table 1 Reynolds numbers for different pipeline sizes, fluids, and velocities

pipe OD [inch]	WT[mm] [mm]	ID [m]	RE Water V = 1	RE Oil in min flow	RE Kerosene in min flow	RE Crude oil in **TL** flow
8	12,5	0,1782	*200225*	*25099*	*108659*	*2510*
12	12,5	0,2798	*314382*	*39408*	*170610*	*3941*
16	12,5	0,3814	*428539*	*53718*	*232561*	*5372*
20	12,5	0,483	*542697*	*68028*	*294512*	*6803*
24	12,5	0,5846	*656854*	*82338*	*356463*	*8234*
38	12,5	0,9402	*1056404*	*132423*	*573293*	*13242*
Fluid	Temp [°C]	Dynamick Viscosity [kg/ms]	Density [kg/m3]	Kinematic Viscosity [m2/s]	Velocity min [m/s]	Velocity test loop (**TL**) [m/s]
					1	0,1
Water	26	0,00089	1000			
Kerosene	26	0,00164	1000			
Crude oil	54,4			0,0000071		

Table 1 gives an overview of the Reynolds number in relation with some common pipeline sizes (ID > 8 inch) using water, crude oil (32.6° API), or kerosene (better known as jet fuel). The velocity used is 0.1 m/s, which was the flow velocity used during the case study in Bergen. The second velocity chosen is the minimum recommended pigging speed, 1 m/s, which was used during the second case study in Montrose. For fluids in a 16" pipeline with a flow velocity of minimum 0.1m/s, the flow regime is classified as turbulent. This correlates to Kjøraas which states "Full scale situations in the petroleum industry almost exclusively deals with turbulent flow [...]" (2013b,p. 23).

The equations presented so far deal with a none-friction environment, but in actual pipeline system, this is not the case. To review the losses within the pipeline system the flow regime needs to be determined. The overall pressure loss within the pipeline system is often called head loss. The head loss can be calculated by the Darcy-Weisbach equation, which includes the Darcy friction factor, and for turbulent flow regimes, this factor can be found using the Moody diagram, Appendix 10.5. Using the Moody diagram for turbulent flow, the friction factor is more or less dependent on the relative roughness and to a very small existent the Reynolds number. This in comparison to the laminar flow where the friction factor is calculated based only upon the Reynolds Number (Menon, 2004).

The overall pressure loss in a pipeline can be divided into two subdivisions. In addition, the sum of this equals the overall pressure loss in the pipeline system. The major losses are due to friction between medium and pipe wall and the minor losses are due to pipeline components such as bends, valves, reductions and similar (EngineeringToolBox, [n.d]) and (Mitroy, 2004).

The pressure loss due to friction is given as $\sum P_f$ and the extended Bernoulli's equation is then:

$$P_1 + \frac{1}{2}P_1 v_1{}^2 + \rho_1 g h_1 = P_2 + \frac{1}{2}P_2 v_2{}^2 + \rho_2 g h_2 + \sum P_f$$

Equation 8 Extended Bernoulli's equation with respect to pressure losses.

The friction loss is given by:

$$P_f = \lambda * \frac{L}{ID} * \frac{\rho v^2}{2}$$

Equation 9 Darcy - Weisbach equation with respect to pressure losses.

Where:
$\lambda = \ \ darcey\ Friction\ factor\ [dimentionless]$
$ID = internal\ pipeline\ dimention\ [m]$
$L = pipeline\ lenght\ [m]$
$v = average\ fluid\ velocity\ [{}^{m}/_{s}]$
$\rho = fluid\ density\ [\frac{kg}{m^3}]$

The friction factor λ is found as described in the Moody diagram. There are also available equations that can be used, for example Colebrookes or von Karmans equations. There may apply requirements and limitations so making sure the preferred equation is applicable for the situation is important. The Colebrookes equation is for example, valid in the whole turbulent regime.

The head loss will not become significant before the length of the pipeline increases. This meaning that during the case studies, pressure loss is assumed insignificant. In an actual pipeline, it will have a significant impact. This is further discussed in the chapter future work.

The following assumption and data is the base for the next calculations. The test loop used for the case study in Bergen is 157 meter long. Water was used as propulsion and the ID was 0.371m. From Table 1 we know the RE and that the flow regime is turbulent. For illustration, the worst-case values are chosen represented by a corroded pipe with a roughness of $\varepsilon = 3\ m$. The fluid velocity is chosen to $v = 5\ m/s$. With the relative roughness, ε/D and the RE, the friction factor can be read off the moody diagram, Appendix 8.3 $\lambda = 0.038$

From Equation 9 the head loss is calculated.

$$P_f = 0.038 * \frac{157m}{0.371m} * \frac{1000*5^2}{2} = 20101\ \frac{N}{m^2}$$

The estimated pressure loss in the test loop in Bergen is about 0.2 Bar

The actual case study velocity was about $v = 0.12\ [{}^{m}/_{s}]$. The roughness of the pipeline was not that high and a more realistic estimate would be. $\lambda = 0.027$

$P_f = 0.027 * \frac{157m}{0.371m} * \frac{1000*0.1^2}{2} = 23\ \frac{N}{m^2}$ which is negligible.

Due to this, the case study in Bergen disregarded the head pressure loss over the test loop. The reason for the detailed calculation done above is that for a longer pipeline the head pressure loss is a parameter that cannot be disregarded.

3.1.2. Pig behaviour theory

The differential pressure (DP) seen over the pig is what generates the pig motion. This along with the flow velocity is the major contributor towards the overall pig behaviour. Understanding the factors that control pig behaviour, enables further improvement in pigging efficiency.

Wint presents an overview and an equation that enables calculations of the typical DP's required in order to drive different pig types (2010):

$$DP = \frac{PT}{\mathrm{OD}}$$

Equation 10 Differential pressure equation(Wint, 2010,p.45)

$DP = Differential\ pressure\ [bar]$

$PT = Pig\ Type\ constant$

$OD = Nominal\ pipeline\ diameter\ [inchs]$

Table 2 lists the pig types and their constant for use in the equation. This equation needs to be considered as a very general overview. Note that the denominator used in Equation 10 is OD, using this parameter means that the different wall thickness sizes are disregarded. The driving pressure on a pig may change significantly within the same OD range. A "Disk pig" (PT = 9) was used in the 16" test loop in Bergen (OD = 16), this gives, a calculated DP:

$$DP = \frac{9}{16} = 0.56\ bar$$

During the case study two spools with the same OD = 16" and different wall thickness (WT) were used. One spool had a WT of 12.5mm and the other had a WT of 17.5mm. The pressure recorded on the prior was approx. 2.7 bar and the latter pressure was recorded to about 3.5 bar. The difference in drive pressure between these spools was approximately 0.7 bar. The change in WT does not affect the OD values, only the ID values. The pig is however, only affected by the ID, and not the WT or the OD. The pig in this case experienced a pressure change larger than the typical calculated pressure for that OD and pig type. For this reason, the author would recommend a change in or update of the formula. Rather than using the OD, the ID that directly affected the pig type and requirements DP should be applied.

Table 2 Pig type constant (Wint, 2010,p.54)

Pig type	Pig type (PT)- constant
Sphere and Foam Pig	1
2 Cup Pig	4
4 Cup Pig	7
Disk Pig	9
Cup Brush Pig	12
Disk Brush Pig	15
UT ILI Tool	19

The force the pig experienced from this DP can be found on account of pressure being defined as force per unit area.

$$Pressure = \frac{Force}{area}$$

$$Force = pressure * area$$

Equation 11 Force, pressure and area

DP over the pig multiplied by the internal cross section of the pipeline gives the driving force the pig through the pipeline. The eventual pig velocity is determined by the pipeline operational parameters in addition to the pressure over the pig and medium flow. The pig velocities may have restrictions and an ILI pig has often requirements concerning launching pressure and flow rates. A typical ILI velocity may range from 1 - 4 m/s depending on technology used and reason for pigging (Hopkins, 1995). The recommended velocity for most utility pigs will be approximately 1-5 m/s (Esmaeilzadeh et al., 2006).

The major configuration on the pig that affects the velocity is the bypass over the pig. The bypass can be intentional, meaning a hole through the centre of the pig is made, and this may be used for different applications. On a utility cleaning pig this may be directed out onto the wall via nozzles to help cleaning the pipe wall (Cordell et al., 2003). In a video inspection pig application, the nozzles can be reduced and be directed towards the camera lens to remove potential debris that may latch on. The unintentional pig bypass often happens in bends where the pig is off centre and some fluid is able to bypass the pig over the disks. The bypass over the disks will also be found when the pig moves in a straight pipeline. Bypass in a straight pipeline is less and easier to control, if needed. Depending on the application of the pig, this may or may not be of importance.

Further, to highlight the importance of understanding the pig behaviour, the following example based on the author's experience is presented. The scope was to inspect a large vertical pipe that went down to an underground oil storage. To perform an Ultrasonic Testing (UT) inspection, a medium is required between the sensors and the pipe wall. In a non-operational pipe, water is often used. The challenge was that the vertical pipe spool was suspended and these supports had a strict weight restriction. Therefore, the inspection could not be done by closing the pipe of at the bottom, filling it with water and then do the UT inspection. The added weight would exceed the weight limitation for the pipe supports. The solution was to purpose make a pig that would hold a 3-meter water column with no water bypassing the pig. By adding additional water, the pig would slowly start to move because of the added weight on the pig. While the pig moved, a small, calibrated, bypass over the disks would drain the water column over the pig. The pig would stop when the water column again became 3 meter. This setup enabled the UT inspection to be completed within the requirements and limitations regarding the added weight on the pipe supports.

Clean uniform pipeline

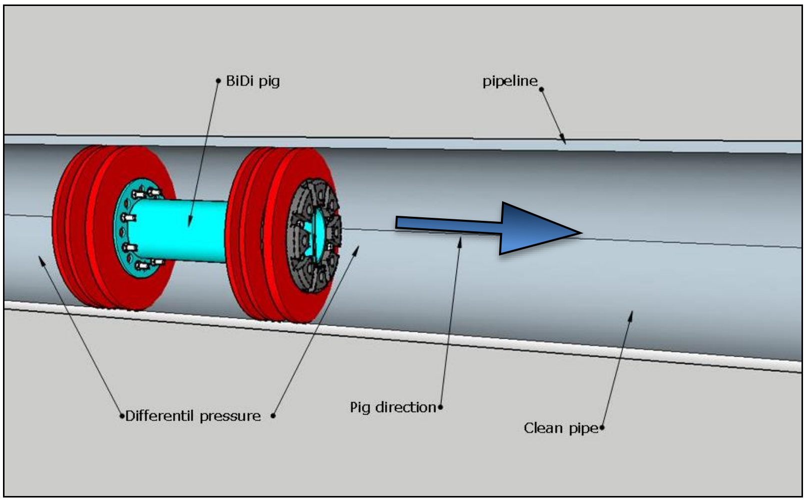

Figure 8 DP a pig in clean pipeline

To simplify the pipeline system, the following is assumed; a horizontal pipeline with no elevation and a uniform internal diameter. In a frictionless, steady state environment, the pressure gradient is at a constant level over the entire length of the pipeline. An assumed frictionless pig will not affect the system in any way. The velocity of the pig will be equal to the flow velocity and the system will remain in a steady state during pigging operation. An assumed frictionless pig is in great contrast to the actual condition of for example a cleaning pig. These pigs are designed to yield friction towards the pipe wall in order to clean the pipeline.

Pipeline anomalies

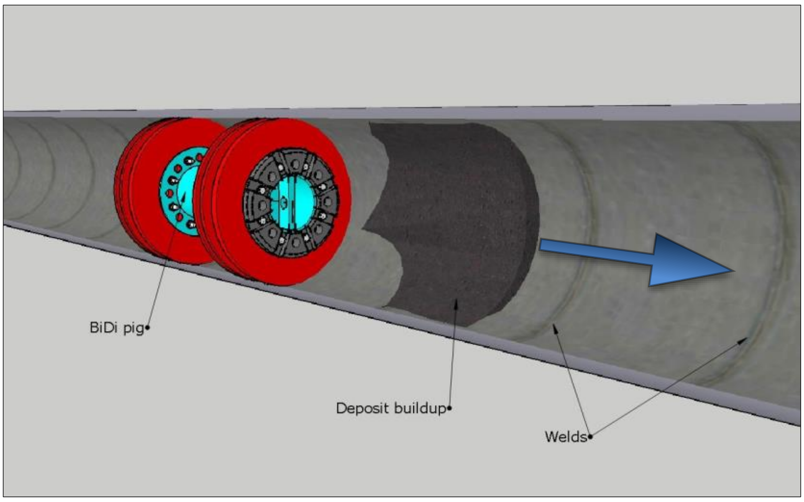

Figure 9 Pig in abnormal pipeline

The most common abnormity in a crude oil pipeline are deposits build and wax sedimentation. A deposit build up will mean a reduction in the internal pipeline diameter. The differential pressure over the pig will increase, enabling the pig to pass the section containing the reduced internal diameter. Pipelines that have significant sediment challenges may require pigs that are purpose made for cleaning the pipeline.

3.2. Method

The method scope is to supply operators with valuable information concerning the pipeline condition. This should be done without interfering with the normal pipeline.
In the case studies, pressure data acquired from a conventional utility pig is considered as the base for a real time conditional monitoring of the internal bore, during the pigging run. The current pipeline inspection approach is to utilise a conventional pig as a tool to provide the cleanness needed for an ILI pigging operation. To view the conventional pig as a sensor is a rather new approach (Nicholson, 2004). The idea is that the behaviour of the pig during the pigging operation should not change significantly unless the surrounding environment changes. To account for the requirement that the method should not interfere with production, the instrumentation for recording the pig behaviour can not be mounted on the utility pig. Nicholsons approach to mount inspection equipment on the utility pig is creating a new category of pig, which Nicholson calls,

smart utility pig technology *(Nicholson, 2004).* Reviewing the term ILI it could be argued that the smart utility pig technology is in fact under the categorised ILI pig.

The following examples are recounted to highlight that modification, and mounting equipment onto a conventional utility pig, is often not just and easy task.

The author supervised a pigging operation where a gauge pig was modified to collect conditional pipeline data. It would traverse a 100km+ pipeline in the Middle East. The third party logger was mounted and sent from an offshore facility to the refinery onshore. When the pig was received, the brackets for logging equipment on the pig have been broken off during the run. The subsequent investigation found that the third part procedure did not account for the length of the pipeline. The constant vibration over a long period and the none-ideal mounting location for the equipment generated material fatigue in the mounting brackets. This resulted in a complete fracture and the equipment was tore off. Using third party equipment, which is not design for the specific task; need to be subject to a thorough risk assessment prior to usage.

A second incited was in a shorter crude oil pipeline. A utility pig was modified and logging equipment was mounted onto the pig. The pigging operation procedure was updated to account for the modification done to the pig. Upon receiving the pig, normal procedure was to remove petroleum product on the pig with hot water while still in the pig-receiver. The cleaning task was removed from the procedure due to the electronic equipment mounted onto the pig. The pig was clean. Most of the electronic components were destroyed. The subsequent investigation showed that due to miscommunication between changing crews the updated procedure was not followed. Some temperature readings was recovered and showed almost 127 °C!

One aspect is the risk involved when implementation modifications to a utility pig, the other aspect is the interference the pig will have on normal production. By not modifying, the utility pigs in anyway, and installing the instrumentation directly on the topside pipeline will make the system independent concerning the utility pig used. No foreign objects are inserted into the pipeline and no interference with the normal production is elements that are in favour of testing this method.

The main concept of the method is:

"By recording and analysing the pig behaviour, undesirable features could be identified and located"

4. Case studies

Different locations were considered for the case studies. Requirements for the facilities were amongst other pipe length, pipe diameter, geographic location, availability, and cost. The case studies were conducted in two parts. The first case study was a method verification performed at a test facility located in Bergen, Norway. On the completion of the first part, a second case study was conducted at a facility in Montrose, UK. In comparison to the facilities in Bergen, the test loop in Montrose was longer and uniform. The combination of these two elements would give indications if the method could function in a pipeline and if it could detect the few features installed in this pipeline.

The content of this chapter is a description of the test loops, equipment, and collected data presentation. During the case studies, large amount of data were collected. In order to keep the thesis structured, the data are presented as follows. Certain indication in the data are highlighted, analysed, and discussed. The analysis contains, if applicable, comparison to the corresponding theory, estimations, measurement, and/or calculations.

The case study in Bergen is the primary case study used to verify the method. The results are thoroughly described to account for findings that correspond with the drawings, in order to verify the method. On the other hand, the case study in Montrose was performed in order to verify the detectability in longer and more uniformed pipelines with less features. It is described in manner of method functionality, and in the analysis, only the results that are important for understanding and verifying the functionality of the method within the test loop.

4.1. Case study at research laboratory in Bergen

The case study in Bergen was performed in a pipeline with a length of 159 meter from the launcher to the receiver. The OD is 16" and with a general bore of 371.44mm. The test facilities are very versatile enabling different scenarios test loop setups. For the trials in Bergen, the same BiDi pig was used to eliminate differences in pig configuration. Both pig traps and the test loop are according to the NORSOK standards.

4.1.1. Test loop, setup and equipment

- Pig run and data logging in a 157 m log 16" test loop at Gravdal, Bergen.
- Computer based data acquisition system
- Pressure transducers
- Bidirectional pig

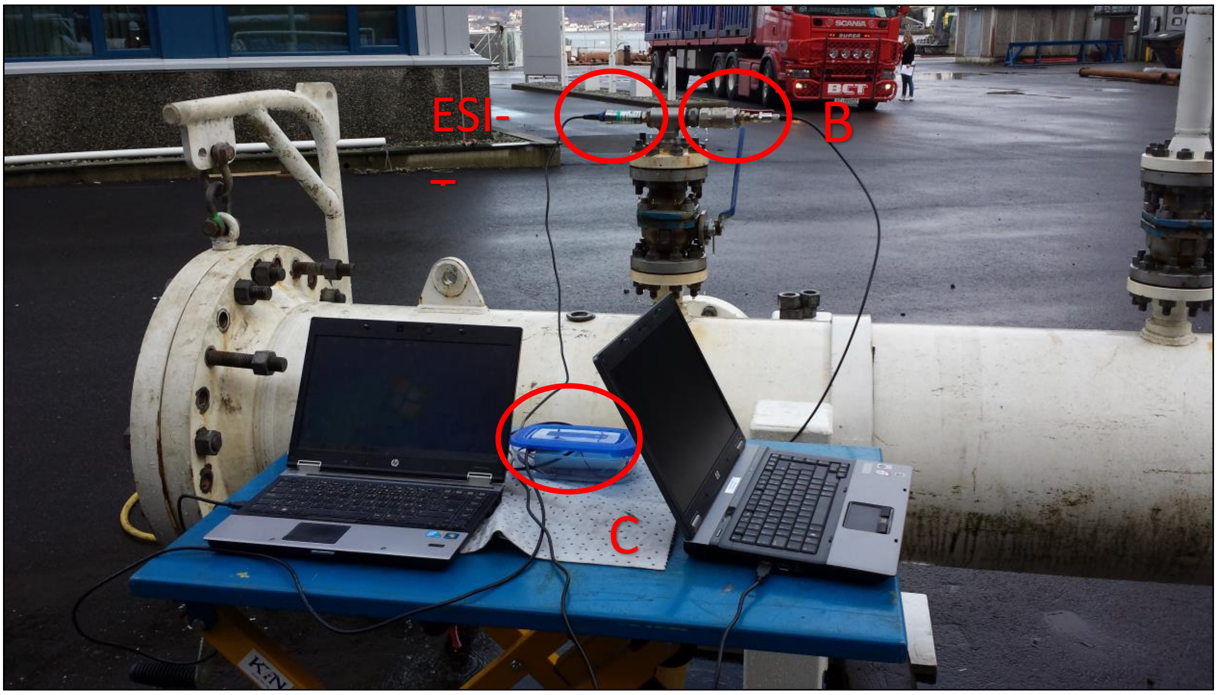

Figure 10 Setup of equipment during case study in Gravdal, Bergen.

The setup of the equipment is shown in Figure 10. Two independent systems, each with its own pressure senor and computer software, were used during the pigging operations. Both pressure transducers were connected to the pig-launcher through a T-piece, meaning that both transducers measured the same pressure. Circle *A* in Figure 10 shows the transducer, which is a part of the GS4200-USB system from ESI-Tec, Appendix 10.4. This system includes a computer software that measures, records, and plots the signal directly to the computer. The transducers sampling rate can be adjusted through the USB connection, and it adjustable up to 5 Hz. The sampling rate is the number of samples obtained in per second.

The pressure transducer in circle *B* and the box in circle *C*, Figure 10, is a part of a system made by the author. The main components are a high-speed pressure transducer, an Arduino electronic board, and a computer. The transducer measuring range is 0 to 5 bar with a corresponding signal output of 0 to 5 VDC. The output pressure signal is connected to the analogue input on the Arduino board. A purpose made programme code was used, Appendix 10.6. It uses the 10-bit analogue to digital converter (ADC) and then maps the input signal to an integer value between 0 and 1023. A linear conversion is used on the integer values to generate an output signal that correspond with the transducer measuring range. Finally, the output signal is sent through the USB to a computer that reads and records the processed data. The computer uses an open-source Terminal software to record and display the receiving signal. Laboratory bench trials were done to verify the operation of the system, thus it is not certified or calibrated by a third party. The sampling frequency used during both the bench trials and the case study in Bergen with this system was 1000Hz. The following presentation and analysis is with data collected by the GS4200-USB system from ESI-Tec. The third party calibration ensures that the data are reliable.

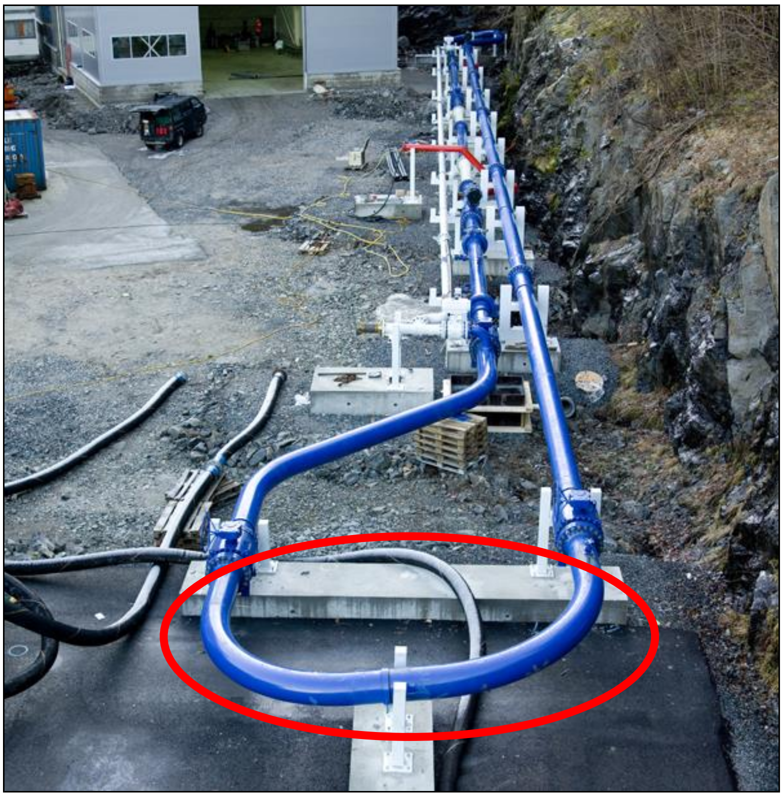

Figure 11 Overview of the KTN Test loop

Figure 11 gives an overview of the test loop at Bergen. The red circle on the picture indicates the spool section that was removed for the case study. A pig-launcher and a pig-receiver were reassembled onto the loop as Figure 12 demonstrates.

Figure 12 Pig-launcher and pig-receiver mounted on the test loop

Figure 12 shows the location of the pig-launcher and the pig-receiver. The marked location is where the pressure equipment was connected during the case study.

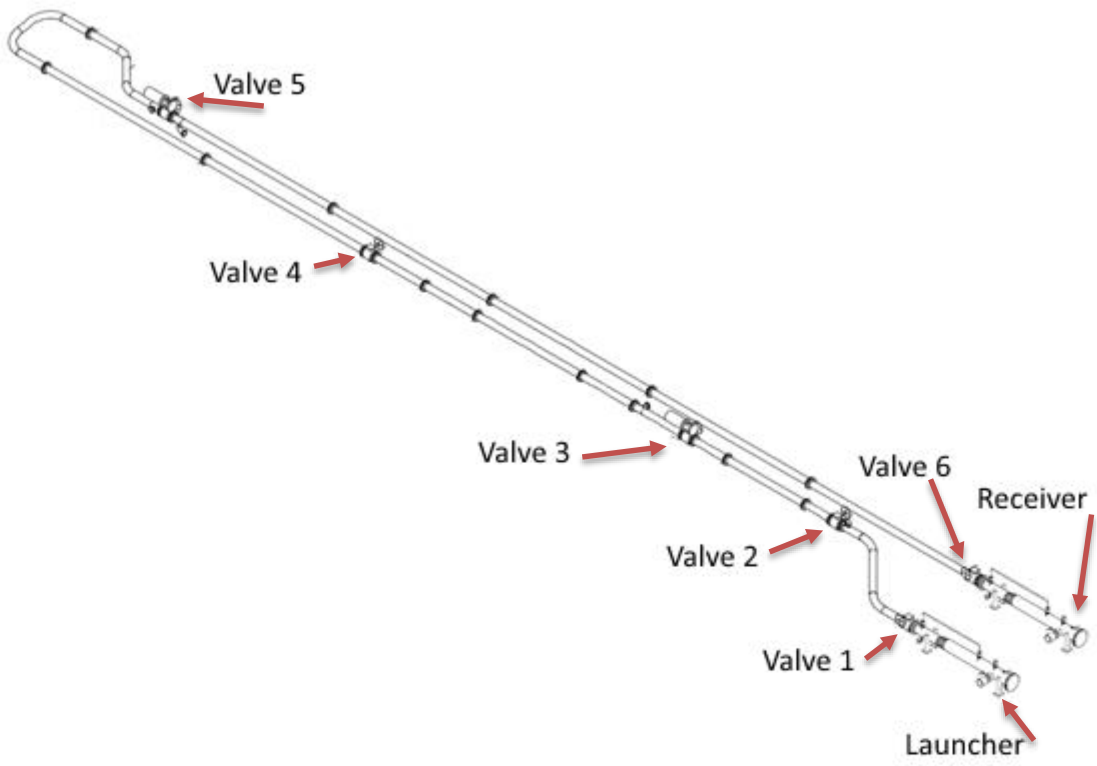

Figure 13 Isometric overview of KTN test loop at Gravdal, Bergen

Figure 13 is the corresponding isometric drawing of the test loop used during the case study. The launcher, receiver, and the six valves are marked in the drawing. The detailed isometric drawings are attached in the Appendix 10.2 and 10.3

4.1.2. Result from test run 1

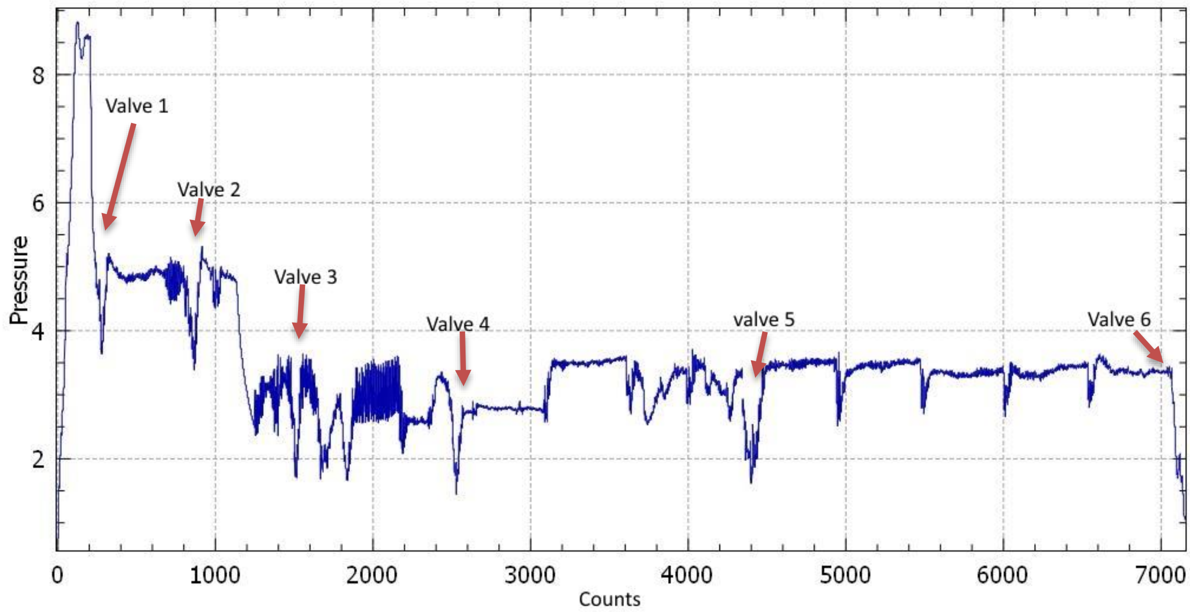

Figure 14 Data from the entire pigging operation, from pig launcher to pig receiver.

Figure 14 shows the data collected by the pressure transducer from the entire pig run. The figure shows the pressure transient over time. The X-axis represents the time in counts. As stated in section 3.2, when the internal diameter changes, the corresponding pressure transient will also change. When the pig enters and passes a valve, the slight increase in ID explains the observed pressure drop. The valve locations are marked in Figure 13 and a detailed view in found in, Figure 23.

Calculations

To further analyse the pressure data, the calculations for average velocity and conversion of units need to be established.

The conversion from counts to second is directly correlated with the sampling rate of the equipment. The sampling rate for the ESI-Tec is 5 Hz.

$$\text{Counts}=t*f_s$$

Equation 12: Conversion from counts to seconds

$t = Time\ [sec]$

$f_s\ = Sampling\ rate\ \ [Hz]$

The time the pig used from the pig-launcher to the pig-receiver can then be found. By reviewing the plot, the launch count and arrival count are found. By subtraction, the overall counts in time for the pigging operation is found to be 7180.

$$t_{launcher-receiver} = \frac{Counts}{f_s}$$

$$t_{launcher-receiver} = \frac{7180}{5} = 1435\ sec$$

143 seconds is approximately 24 minutes.

The average pig velocity over a section is given by:

$$\overline{v}_{section} = \frac{d}{t}$$

Equation 13 Average pig velocity

$\overline{v}_{section} = average\ velocity\ [m/s]$

$d = distance\ [m]$

$t = time\ [s]$

The average pig velocity during the pigging operation can be found by combining Equation 12 and Equation 13. This gives the pig velocity in m/s.

$$\overline{v}_{section} = \frac{d}{\frac{counts}{f_s}}$$

Equation 14 Average speed

$\overline{v}_{Launcher-receiver} = Average\ speed\ of\ the\ pig\ [{}^{m}/_{s}]$

$$\overline{v}_{Launcher-receiver} = \frac{157.630m}{1435s} = 0.110\ m/s$$

The overall distance of the test loop is found by adding the length the pipe spool in appendix 10.3. The average velocity of the pig from the launcher to the receiver is found to be 0.11m/s. The velocity will vary over the course of the test pipe. The equations above will also be used when calculating the average velocity of given pipe spools in the test loop.

4.1.3. Test loop segment analysis

From Valve 5 to Pig-Receiver

Table 3: Test loop components from the Valve 5 to Pig-Reciver ref Figure 15 and Appendix 10.3.

Component	# - figure	WT [mm]	Length[mm]	# - isometric.	Note
Pig-Receiver			4000+4000		From 16”to 20” oversized
Valve	6		838	602	Manual operated
Spool section	I	17.5	12200	101	
Flange	A			301	
spool section	II	17.5	12200	101	
Flange	B			301	
Spool section	III	17.5	12200	101	
Flange	C			301	
Spool section	IV	17.5	12200	101	
Flange	D			301	

spool section	V	17.5	12200	101	
Valve	**5**		**838**	**601**	**pneumatic operated**

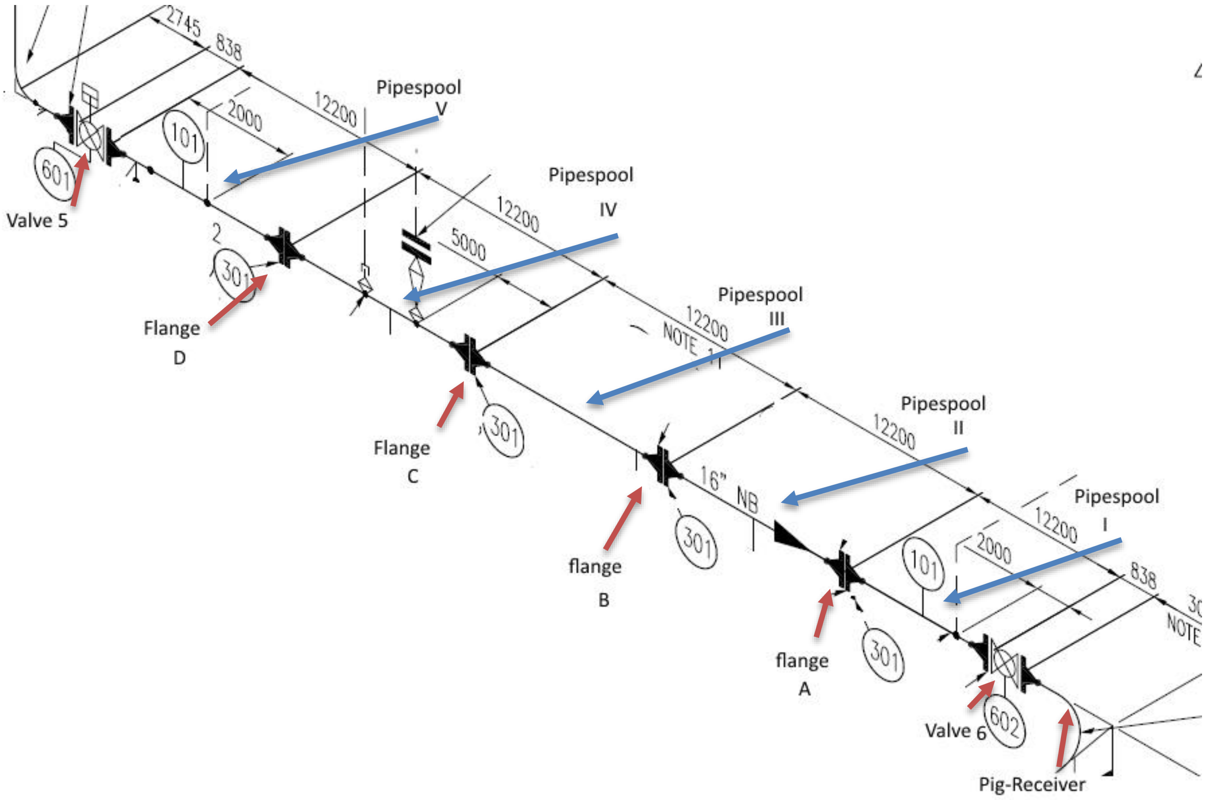

Figure 15 Isometric drawing of testpipe from Valve 5 to Pig-Reciver

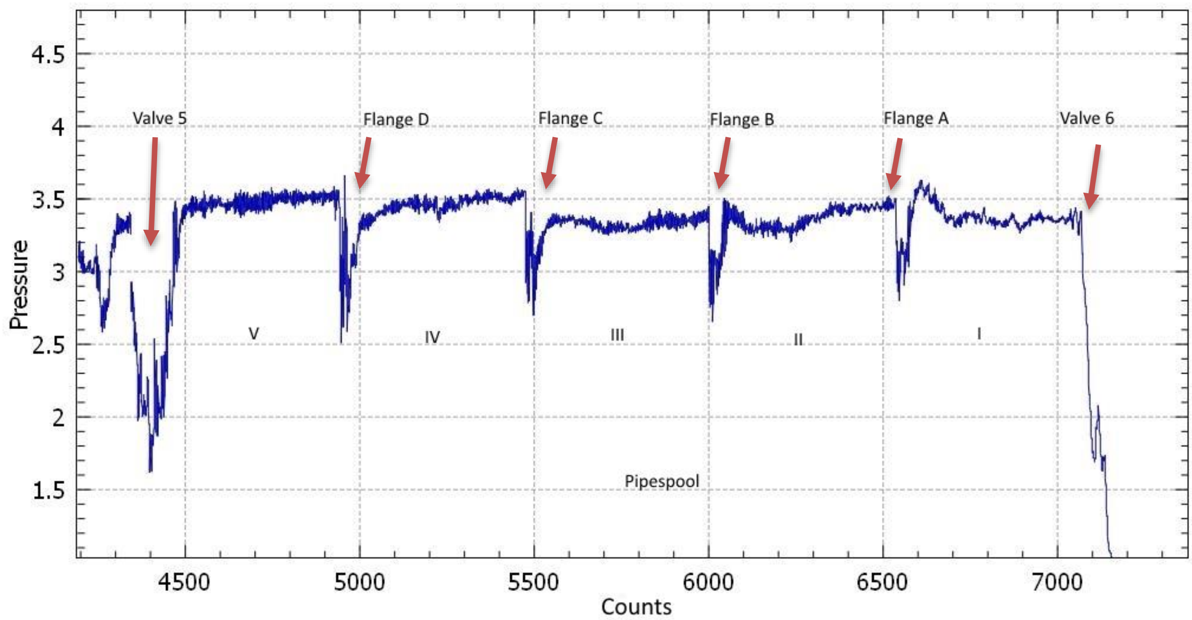

Figure 16 Corresponding pressure data from Pig-Reciver – Valve 5

The section between valve 5 and the pig-receiver consists of five 12200 mm sections; each pipe spool conjoined by flanges. Figure 16 shows some characteristic pressure drops, these are marked by arrows and are found at approximately 5000, 5500, 6000, and 6500 counts. These correspond to the marked Flanges A-D in Figure 15. The pipe spool lengths are each 12200 mm this is illustrated and marked *pipe spool I to V* Figure 15. The count length between the marked pipes spools is about 500 counts. A more detailed overview of *Pipe Spool I* is shown in Figure 17.

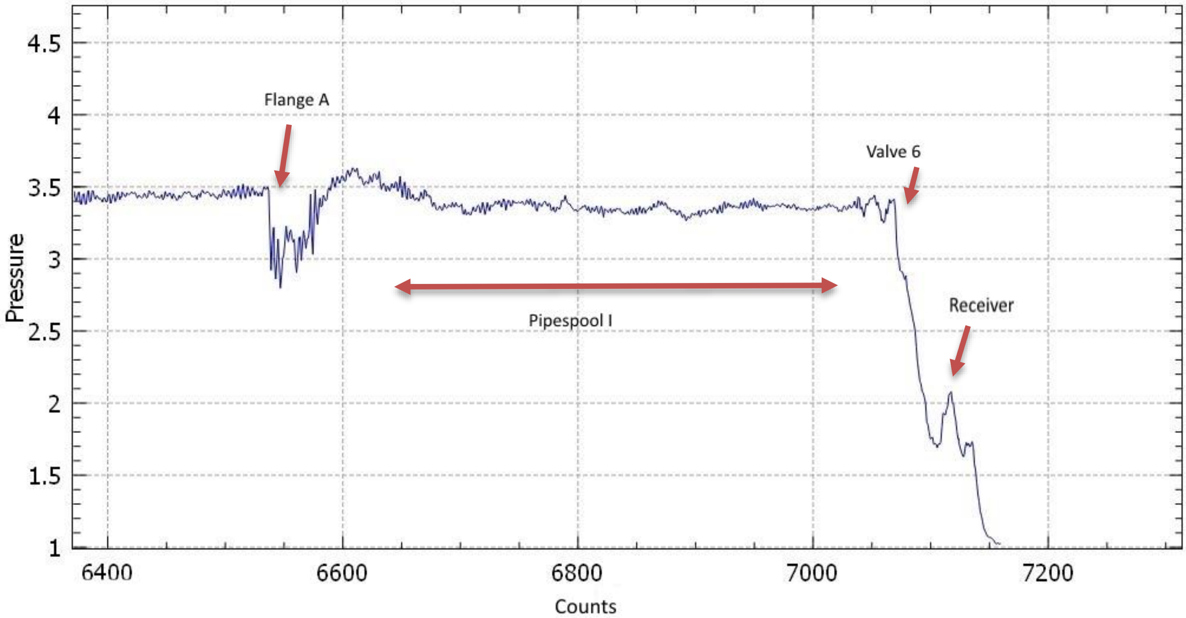

Figure 17 Flange A- Pipespool I – Valve 6

Figure 17 gives a detailed view of Flange A, *Pipe Spool I*, Valve 6 and the Pig-Receiver.

The length of the spool is known, and therefore the average velocity in this section can be calculated. *Pipe spool I* length is 12.2 m, the middle of Flange A is approximately at count 6640 and the spool ends just before the pressure drop at valve 6, around count 7145. The time the pig uses to through *pipe spool I* is then 7145-6640 = 505 counts.

The pig velocity over *pipe spool I* is found by using equation 3.

$$\overline{v}_{pipespool\ I} = \frac{d}{\frac{counts}{f_s}}$$

$\overline{v}_{pipespool\ I} = average\ speed\ [m/s]$

$t = Time\ [sec]$

$f_s\ = Sampling\ rate\ \ [Hz]$

$d = distance\ [m]$

$t = time\ [s]$

$\overline{v}_{pipespool\ I} = \frac{12.2}{505/5} = 0.121\ m/s$

The average velocity over section *Pipe Spool I* is about 10% higher than the average overall loop velocity.

From Valve 4 to Valve 5

Table 4: Test loop components from the Valve 4 to Valve 5

Component	# in figure	WT [mm]	Length[mm]	#- isometric	Note
Valve	4		838		Manual valve
Spool section	VI	12,5	12200		NOT ON DRAWING*
Flange				301	
Spool section	VII	17,5	12200		
Flange				301	
Spool section		17,5	3302		90° 5D BEND
Spool section		17.5	3438	101	
Spool section			3302	203	90° 5D BEND
Flange				301	
Spool section		17.5	2743	204	45° 3D BEND
Spool section		17.5	3374		
Spool section		17.5	2745		45° 3D BEND
Valve	5		838	601	pneumatic operated

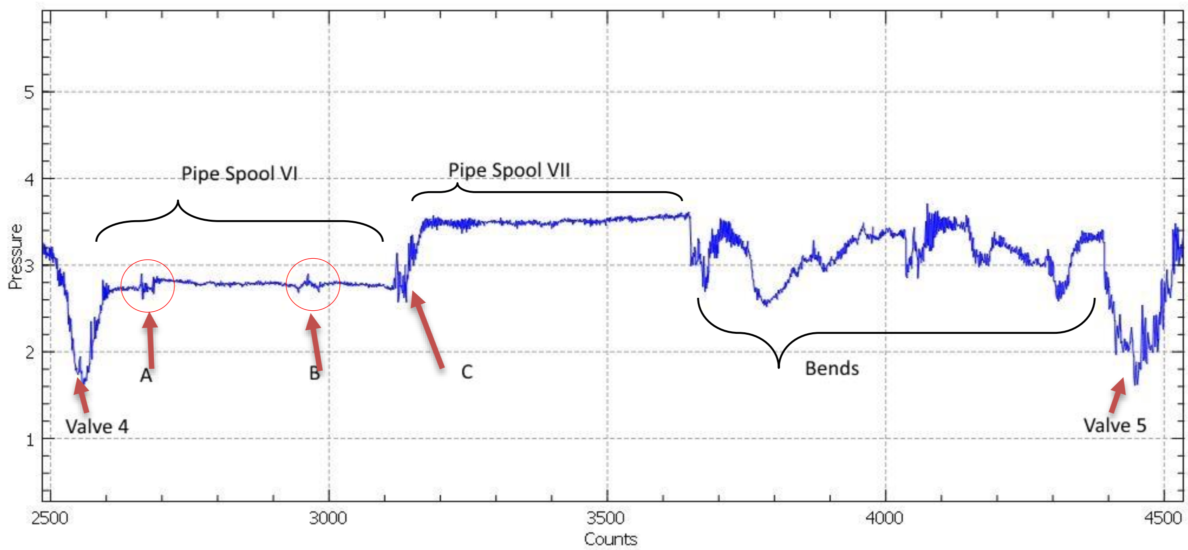

Figure 18 Pipe section from Valve 4 to Valve 5

Comparing the two 12200 mm (12,2m) section *Pipe spool VI* and *Pipe Spool VII*, there are some significant differences concerning their pressure signature. The average pressure is higher on the latter spool. The isometric drawings state that both pipe spools are the same. Knowing that prior to the pig run, the original pipe spool was removed and replaced (with *Pipe Spool VI*), provides insight to the findings. This was done in order to see if the presented method could detect the changes the spool introduced into the pipeline. The specification of the new pipe is that the Outer Diameter (OD) is the same as the original, Ø406.4 mm. The length is required to be the same, 12200mm, but the Internal Diameter (ID) is 381.4mm. This means the wall thickness (WT) in the spool is less than the original. A cross section of a pipe is illustrated below to show the different denominations and their relation.

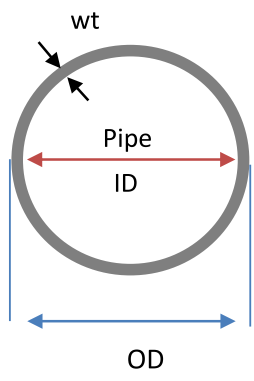

Figure 19 is the cross section of a pipeline with OD, ID and WT shown.

$$WT = \frac{OD - ID}{2}$$

Equation 15 Wall thickness calculation

$WT = wall\ thickness\ [mm]$

$OD = Outer\ Diameter\ [mm]$

$ID = Internal\ Diameter\ [mm]$

$$wt_{Pipe\ spool\ VI} = \frac{406.4 - 381.4}{2} = 12.5\ mm$$

It is calculated that the wall thickness in *Pipe Spool VI* is 12.5mm in comparison to the wall thickness in P*ipe Spool VII,* which is 17.5 mm (Appendix 10.3). From the perspective of the pig, the ID change from spool VI to VII is a 5mm step. To enter the reduced ID, the disks will have to further be compressed in order to accommodate for the smaller pipe spool ID. The additional energy required to do this is observed as an increase in pressure. In the larger *Spool VI,* the measured average pressure is 2.8 bar. When the pig enters and travels *Pipe Spool VII,* the average pressure is increases, to about 3.5 bar. This information can be utilised in measurements with regards to finding the bore penetration of indications. $\Delta P = 0.7$ bar for a 5mm step. Assuming linearity and knowing the ID is 371.4mm, the pressure will increase 0.14 bar per 1 mm circumference ID reduction.

Further, the associated velocity within these two pipe spool are summarised.

Figure 7 shows that when the ID was reduced, the velocity increased. Using the data from Table 4, the ID of *pipe spool VI* is 371.4mm and the average velocity over this is calculated to:

$$\overline{v}_{pipespool\ VI} = \frac{12.2}{(3116 - 2605)/5} = 0.117\ m/s$$

Using $\overline{v}_{pipespool\ VI} = 0.117 m/s$ in Equation 3, as done in section 3.1.1, theoretical increase in velocity is found to be: $\overline{v}_2 = 0.123\ m/s$.

Comparing the theoretical expected velocity $\overline{v}_2 = 0.123\ m/s$ with the calculated velocity in the reduced ID spool $\overline{v}_{pipespool\ I} = 0.121\ m/s$ a slight increase in velocity, is as expected found. On a general note, the accuracy of these results depend on accuracy regarding finding the correct location on the data plot. It would therefore be recommended to have a lower degree of accuracy in future calculations. The calculations done above are to show that the overall principle is valid concerning the velocity and ID reduction.

In Figure 18, markings *A* and *B* indicate two small sections where the pressure slightly changes. This is also observed on a subsequent pig run. A detailed look at *Pipe Spool VI* shows the two indications clearly, Figure 20.

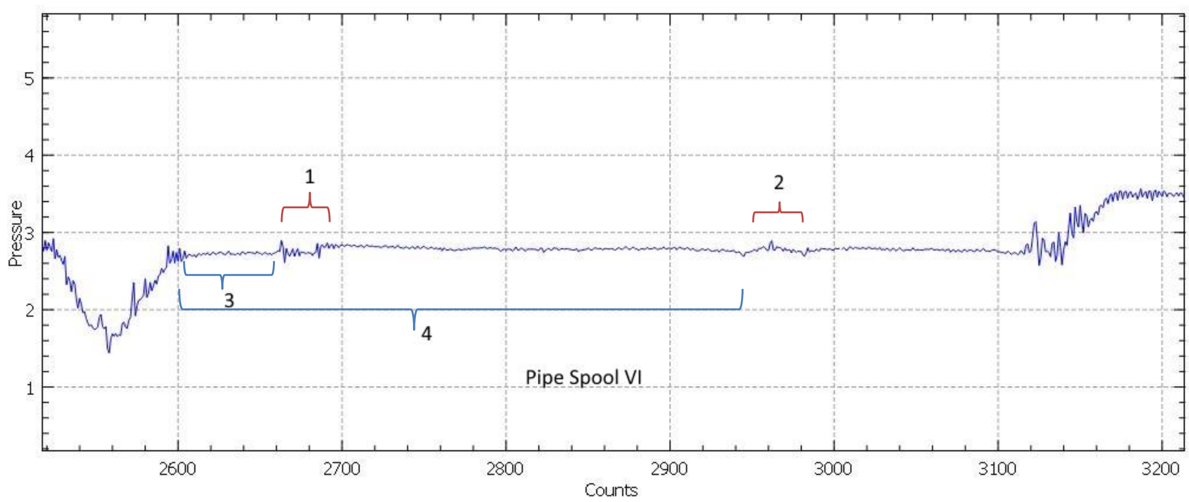

Figure 20 Features on Pipe Spool VI

The length of the spool is the same as the original, using this information it is possible to estimate the locations of the two indications. Constant pig velocity over the length of *Pipe Spool VI* is assumed.

$$v_{avg} = \frac{d}{t}$$

Equation 16 velocity calculation for mm/counts

$v_{avg} = average\ velocity\ [mm/counts]$

$d = distance\ [mm]$

$t = time\ [counts]$

The count position of the flange is selected as soon as the fluctuation is stabilised. A count position is selected for the end flange under the same criteria. A count point is chosen prior to the rapid pressure change observed when the pig enters the flange existing the *Pipe Spool VI*. The centremost position within the indications is selected for the calculations.

Based on these criteria, the selected count points for the flanges and indications locations are stated in Table 5 below.

Table 5 Selected counts positions

First flange(**ft**)	End Flange (**en**)	First Pressure rise (**I1**) Run1/***Run2***	Centre of Indication 1(**I1**)	First Pressure rise (**I2**)	Centre of Indication 2 (**I2**)
2605 counts	3116 counts	2663/***2633***	2674 counts	2962	2973 counts
		Second Pressure rise **I1**		Second Pressure rise **I2**	
		2685/***2655***		2984	

$$d_{ft-I1} = t * v_{avg} = (2674 - 2605)counts * \frac{12200mm}{(3116 - 2605)counts} = 1647mm$$

$$d_{ft-I2} = t * v_{avg} = (2973 - 2605)counts * \frac{12200mm}{(3116 - 2605)counts} = 8785mm$$

The calculated length gives the first indication location at about 1.8 m from the start flange and the second indication at 8.5 m from the start flange.

Pictures and the measured distance of *pipe spool VI* are shown in Figure 21 and Table 6.

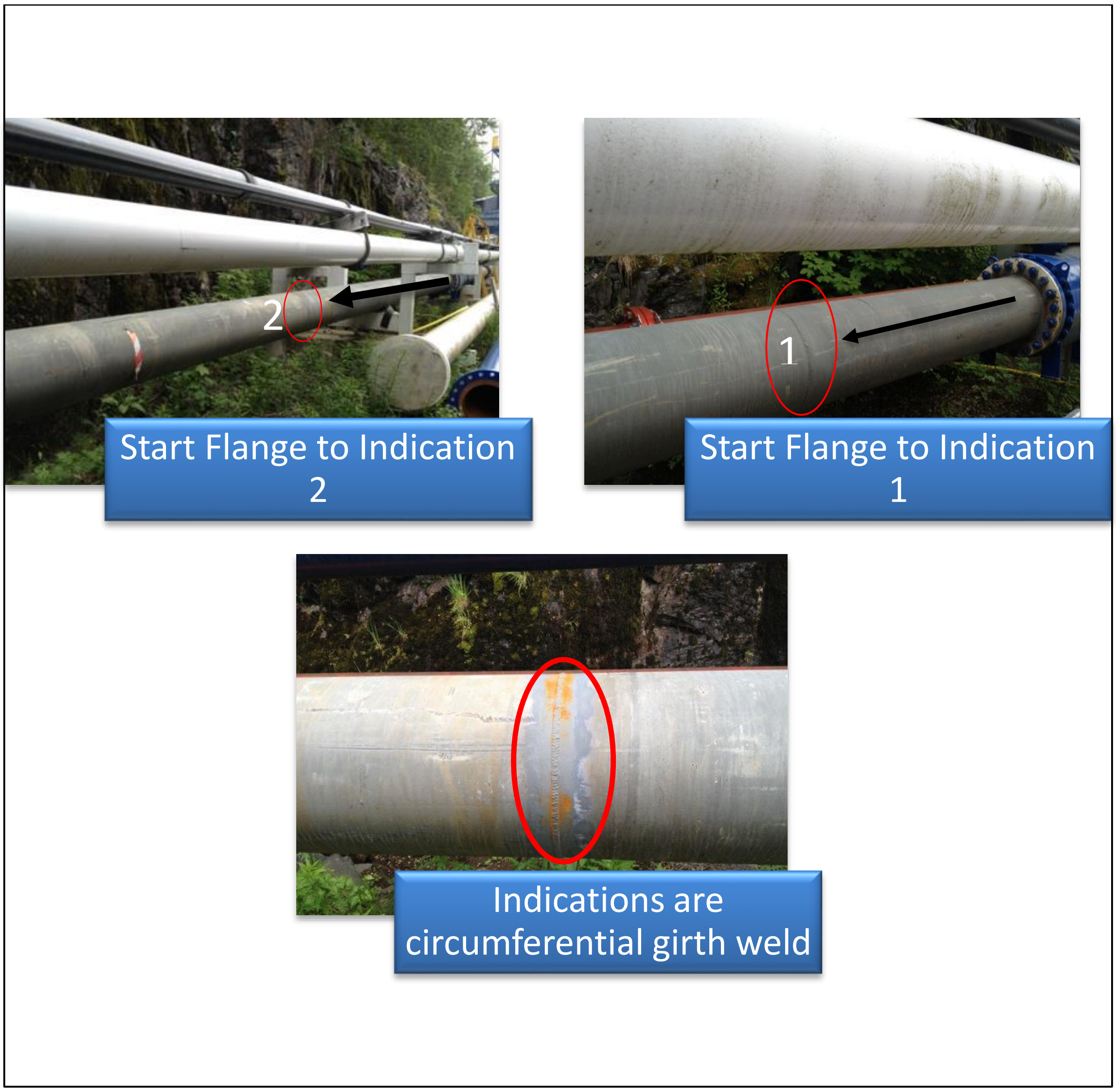

Figure 21 Indication 1 and 2 on Pipe Spool VI

An external visual examination of pipeline reveals the reason for the observed pressure change. On *Pipe Spool VI* there is discovered one circumferential girth weld on each of the indication locations.

Table 6 Indication measurements

	Calculated[mm]	Measured [mm]	Offset[mm]	Pig length
Start flange to I1	1647	2030	383	500
Start flange to I2	8785	8710	-75	500

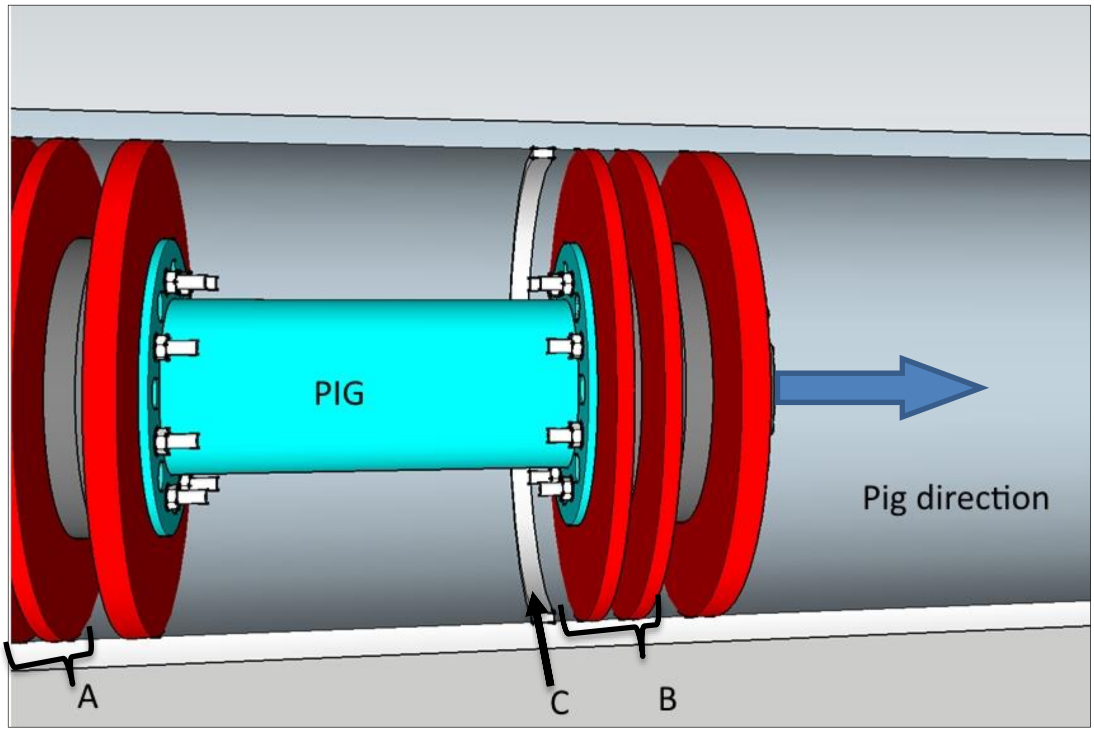

Figure 22 Pig passing a girth weld

Figure 22 is a representation of a bidirectional (BiDi) disk pig passing over a girth weld. When the pig passes a reduction in ID, in this case a circumferential girth weld, the corresponding pressure signal will increase. The pressure signature will represent and reflect the physical characteristics of the pig and the indication. The amplitude of the pressure will give indication towards the size of ID reduction. When the indication is shorter than the length of the pig, the pig disks can be observed within the pressure signature. This is illustrated in Figure 22, when the disks marked *B* on the pig passes the weld the pressure will increase slightly; subsequently the same will happen when the next disk set marked *A* passed weld C. By measuring the time between the two pressure peaks, the distance of the pig could be calculated. From Table 5, the first indication distance is calculated

$$d_{RUN1-I1} = t * v_{avg} = (2686 - 2663)counts * \frac{12200mm}{(3116 - 2605)counts} = 525mm$$

$$d_{RUN2-I1} = t * v_{avg} = (2654 - 2633)counts * \frac{12200mm}{(3097 - 2611)counts} = 527mm$$

The calculated distance between the two pressure peaks for indication I1 is done for two separate runs, here named run 1 and run 2. In both incidences the length was calculated to $\approx$ 525mm

The pig used during both runs is according to recommendation (Cordell et al., 2003) 1.5 x pipeline diameter = 610mm long and the distance between the disk was measured to about 510-530mm.

Valves

The pressure signature for *valve 4* is “shorter” than *valve 5*, and a detailed look at both is shown in below. Mentioned there is a slight increase in ID when entering a valve, the valves are ASME 16”

300LB, Appendix 10.2. The ASME standard sets regulations to the size of the valve ball. These valves have a bore ID of 15.25inch or 387.35mm.

Summarising change in ID from its subsequent spool is found that. When the pig enters a valve from a 16” pipe spool with a WT of 17.5mm the ID is an increase of 15.95mm. If the pig entering the valve from a pipe spool with a WT of 12.5mm the increase in ID is 5.95mm. Comparing all valves under these criteria, the ΔP drop is different but the DP over the pig when passing through the ball valve is similar.

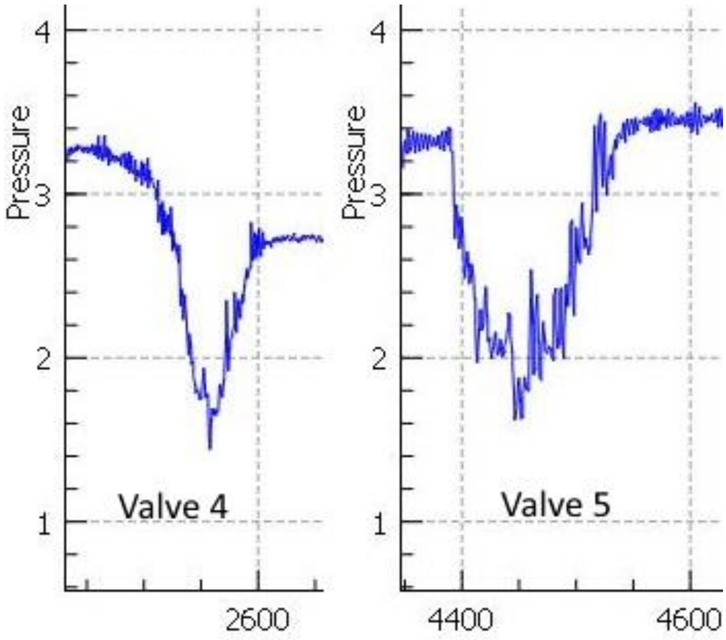

Figure 23 Comparison of pressure signature of valve 4 and 5

The count length of *valve 4* is about 75 counts or 15 seconds. *Valve 5* has a count of about 125 or 25 seconds. The time used to re-establish the pressure gives an indication towards the volume of internal diameter change. By comparing this information with the components on the isometric drawing, a possible explanation can be found. This is shown in Figure 24.

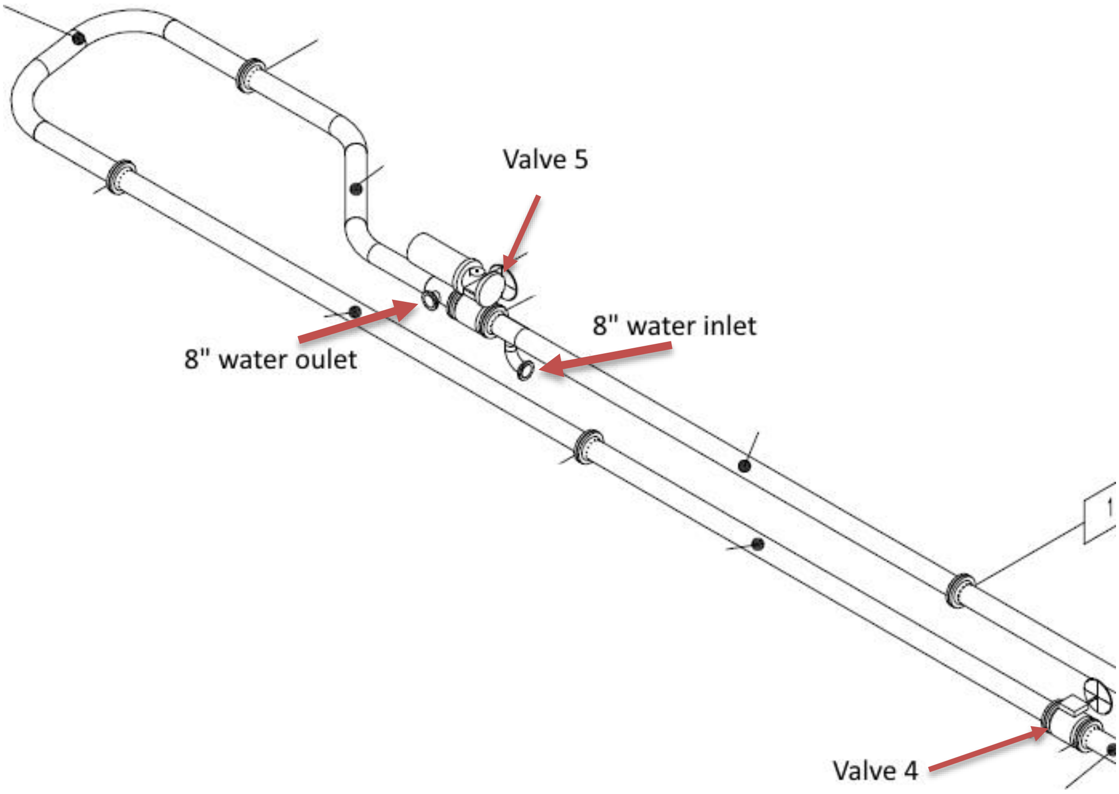

Figure 24 Isometric drawing of pipe from valve 4 to valve 5

As discussed, *Valve 5* has a longer pressure signature than *valve 4*, maybe due to the configuration of the pipes surrounding the valve. The cropped isometric drawing above shows the pipeline configuration around both valves. *Valve 4* is connected to the flanges between two pipe spools. The pressure observed does not have any in- or outlet disrupting the valve pressure signal collected. Just prior to getting to *valve 5*, the pig passes 8” pipe outlet at 3 o’clock. This is closed off during the trial runs, but when the pig passes the outlet, the result is a sudden pressure drop. Just after the valve an 8” water inlet can be found, this was also closed off for the trial run, due to its location at 6 o’clock, it is assumed to be completely water filled and will therefore probably have less impact on the pressure signature.

4.1.4. Result test run 2 and comparison

Several runs in the test loop were performed under different circumstances that are presented. The general overview is that the signal is repeatable for every run. The identification of components and features increases in certainty when the runs are compared; finding similarities while filtering away aperiodic noise from the operational parameters.

The figure below is the data collected from the same test loop under the same conditions. The same features and components as in the first run, Figure 14, can be identified on following pressure signature.

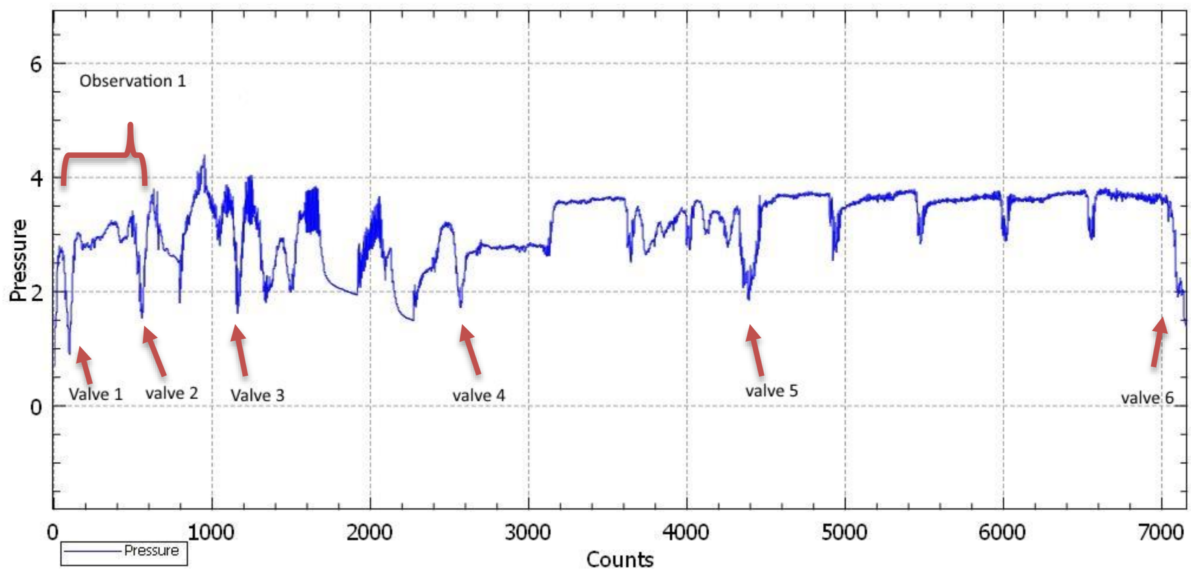

Figure 25 Data from subsequent pigging operation; Pig-Launcher to Pig-receiver.

The data displayed in Figure 25 is collected subsequent of the data collected and shown in Figure 14. There are two observations that will be reviewed. The first one is marked *Observation 1* in the figure above. Comparing this to same count interval for the data collected on the prior run (Figure 14) there is a significant ΔP. Prior to valve 2, the first run shows a pressure in excess of 8.5 bar. Compared to the subsequent run that had a maximum pressure of 3.2 bar prior to valve 2. The reason for this is not found in the pressure data and the presented data are correct. The reason for the high-pressure peak in the first run is probably due to an operational parameter.

Prior to the first pig launch, the test loop was water filled and the excess air released at the highest point in the test loop. The pig was launched by applying flow to the pig launcher upstream, and opening an outlet valve on the pig receiver downstream, thus creating a DP over the pig. In this case, the outlet valve downstream was by accident only partially opened. The restriction of water leaving the loop downstream generated an increase in pressure, subsequently the upstream pressure increased accordingly, and the pig launched. The valve was opened fully when the pig was between valve 2 and 3, this is the observed pressure drop in Figure 14. Figure 25 showed the data from a subsequent run where the launching was done according to the planned procedure.

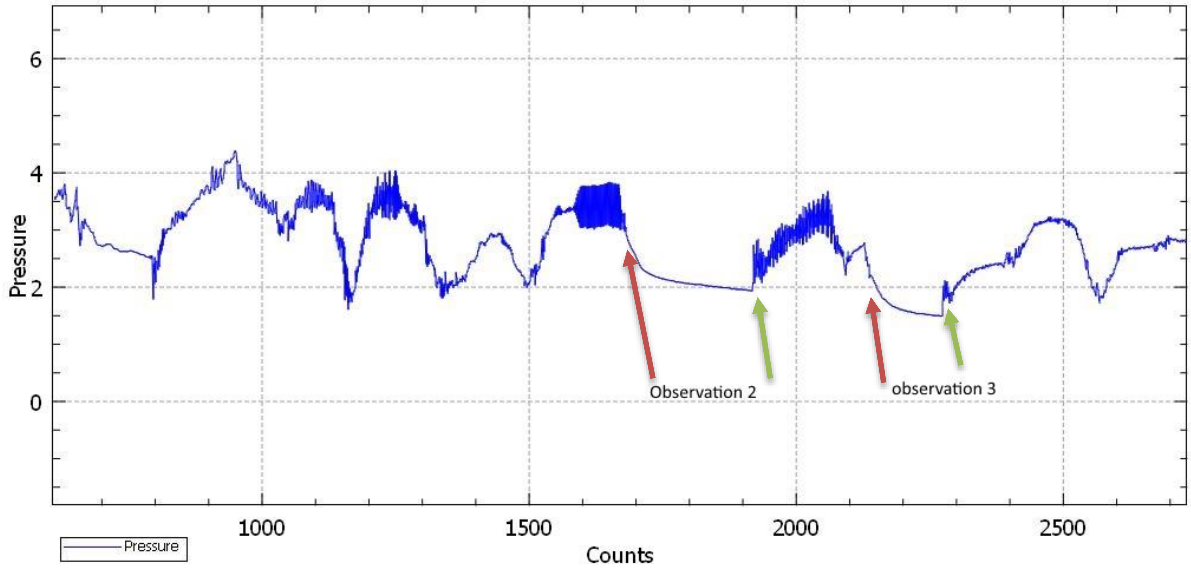

Figure 26 Identification of observations

Figure 26 takes a closer look at the data from the second run in Figure 25. The reason for both observations 2 and 3, is the same. And as the prior explanation is caused by the an external interferance. The red arrow indicates the start of *observation 2. It is* caused by the upstream flow valve being closed resulting in a gradual pressure loss. The flow valve is opened at the green arrow and the pressure rapidliy increases and subsequently the pig starts to move. Observation 3 is a similar phenomenon the red arrow here indicates the opening of an upstream valve, again the pressure drop and is restored when the valve is closed. These tests were done to verify that the plot could detect situations involving external operational parameters. In an operational situation, a similar signal could be observed if the pig passes a section that containes a loss of containment failure, meaning a section where the pipeline is leaking.

4.2. Case study at research laboratory in Montrose, UK

The presentation of the data and result will have another structure than the one used for the first case study. The most significant results are evaluated, interpreted, and discussed. Following this section all relevant plots, tables, and pictures are included.

4.2.1. Test loop, setup and equipment

After the verification of the method in the test loop in Bergen. The second case study was initiated. This was done at research facilities in Montrose, the pipeline was a 1000m-long 10” in diameter and has been constructed in a loop formation. There are two electric drive pumps, a launch and receive trap, two holding tanks, and a flow rate adjustable up to 350m^3/hr .

4.2.2. Result from test runs

During the test in Montrose, two independent data collection systems were used. The ESI-Tec GS4200 system was the same as in the first case study.

The second data collection system was one provided by EZtek. This system consisted of a logging unit, Tallybook and a pressure sensor, HP1003. The calibration certificate are attached, Appendix 10.7. The logger unit and the sensor are shown in the first pictures in Figure 27.

Table 7 is an overview of all runs performed during two days of testing in Montrose. On day one, 03.03.2014, two runs were done, both with an ordinary BiDi pig. The next day, 04.03.2014, an additional nine runs were performed. The main setups for each run are described in Table 7, but the exact details of each run will not be covered in this thesis. The content of Table 7 is as follows:

- Run # and Date: The run done on that particular date, 2 runs on 03.03.2014 and 9 runs the following day, 04.03.2014
- Time: The time when the run starter
- Sensor and Sampling rate: The sample rate and the corresponding logging system used for that particular run
- Sensor location: The location senor was had during the run. The location of the pig launcher and receiver (trap 1 and 2) are found in Figure 29
- Rune time: The overall time used for that run.

In addition, the following parameters were evaluated during the analysed. The most significant results will also be discussed:

Due to the huge amount of data collected and licence restrictions, the raw data will not be attached. As an example, run # 4 had a sampling rate of 4000 samples per second. This particular run took just over 13 minutes, meaning that the data logger sampled and recorded about 3’120’000 occurrences.

The flow rate: Each run logged the flow rate, on run # 7, 8, and 9, the flow rate changed significantly at a predetermined interval. This change in flow rate was done to verify that the method works properly even when changing the parameters during an operation. The results of these tests with variable flow gave promising indications. The flow rate for Run # 2, 04.03.2014 was stable and the average flow rate was 243 m^3/hr, the data collected during that run are presented in Figure 30.

The change in pig type: the first five runs were performed with a BiDi pig; the subsequent six runs used a BiDi cleaning pig, as shown in Figure 27. The data shows that the BiDi cleaning pig with brushes has a slightly higher pressure transient. When the brush pig passes an indication in the pipeline such as a flange, the 2”outlet, a bend, or the vertical pipe section, the pressure peaks are considerably higher than when ordinary BiDi pig passed. This is consistent throughout the results and is illustrated in Figure 32 (BiDi pig passes the 2” outlet at 780m) and Figure 33 (BiDi brush pig passes the same location, 2” outlet at 780m). The pressure peaks at 91 psi in the prior, and 94 psi in the latter figure.

Figure 28 shows the illustration of the pipeline bridge, in Figure 27 the bridge shown in photo and the data collected is represented in Figure 31. The isometric drawings are found in the Appendix.

The data gives indications that the pipeline bridge is detectable, the three arrows marks the, launch, vertical section going up and then the vertical section when the pig goes down.

To position the data in the pipeline, a pipe tally method is used. By identifying each component as welds and flanges, a comparison with the isometric drawing can be done to create an accurate pressure – distance plot. Nicholson describes a similar approach; “The acquired data is positioned in the pipeline using a 'weld counting' methodology in which each pipeline weld is identified from characteristic kicks in the vibration data and then tagged and reconciled with reference pipeline information. This allows the data to be presented with respect to distance rather than time” (2004,p.1).

The above discussions have indicated that the thesis method and technology have potential concerning its repeatability and detectability.

4.2.3. Data presentation

Table 7 Run done in Montrose

Run #	Date	Time	Sensors	Sample rate	Sensor location	Run time	Pig
1	*03.03.2014*	14:46	Tallybook	1000 s/s	Trap 1	13 min 15 sek	Bidi
			ESI	5s/s	Trap 1		
2	**03**.03.2014	15:24	Tallybook	1000 s/s	Trap 1	13 min 10 sek	Bidi
			ESI	5s/s	Trap 1		
1	**04**.03.2014	09:59	Tallybook	1000 s/s	Trap 1	13 min 15 sek	Bidi
			ESI	5s/s	Trap 1		
2	04.03.2014	10:17	Tallybook	1000 s/s	Trap 1	13 min	Bidi
			ESI	5s/s	Trap 1		
3	04.03.2014	10:36	Tallybook	4000 s/s	Trap 1	12 min	Bidi
			ESI	5s/s	Trap 1		
4	04.03.2014	11:08	Tallybook	4000 s/s	Trap 1	13 min	Bidi with/ Brushes
			ESI	5s/s	Trap 1		
5	04.03.2014	11:26	Tallybook	4000 s/s	Trap 1	13 min	Bidi with/ Brushes
			ESI	5s/s	Trap 1		
6	04.03.2014	13:25	Tallybook	4000 s/s	Trap 1	13,5 min	Bidi with/ Brushes
			ESI	5s/s	**Trap 2**		
7	04.03.2014	14:00	Tallybook	1000 s/s	Trap 1	19 min	Bidi with/ Brushes
			ESI	5s/s	**Trap 2**		
8	04.03.2014		Tallybook	1000 s/s	Trap 1	23 min	Bidi with/ Brushes s
			ESI	5s/s	**Trap 2**		
9	04.03.2014		Tallybook	1000 s/s	Trap 1	30 min	Bidi with/ Brushes
			ESI	5s/s	**Trap 2**		

Figure 27 Pictures from case study Montrose,

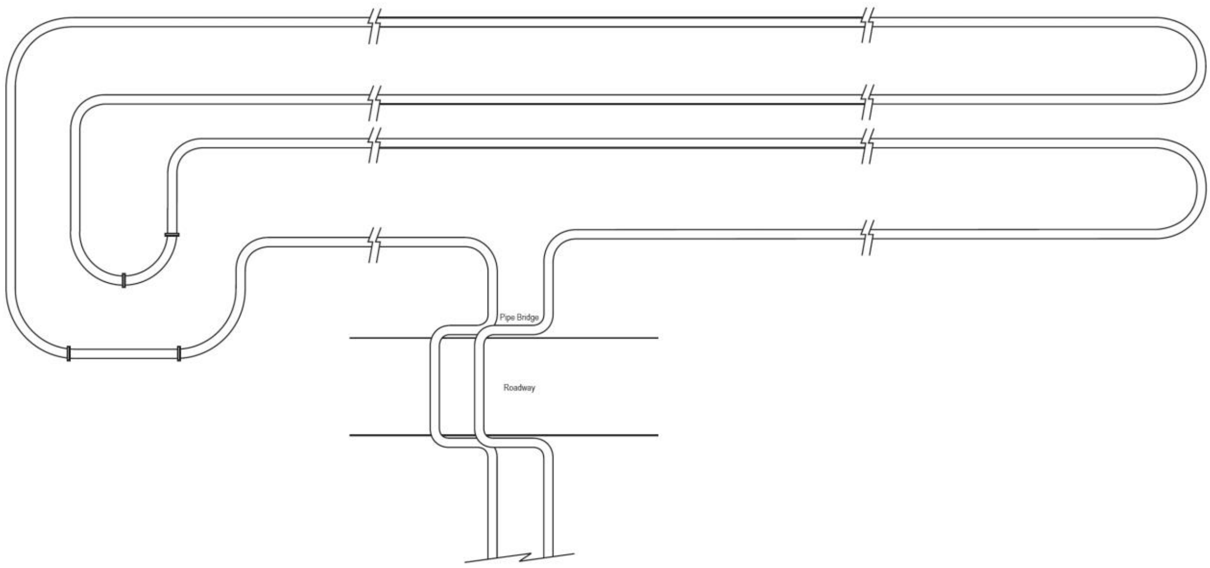

Figure 28 the test loop configuration

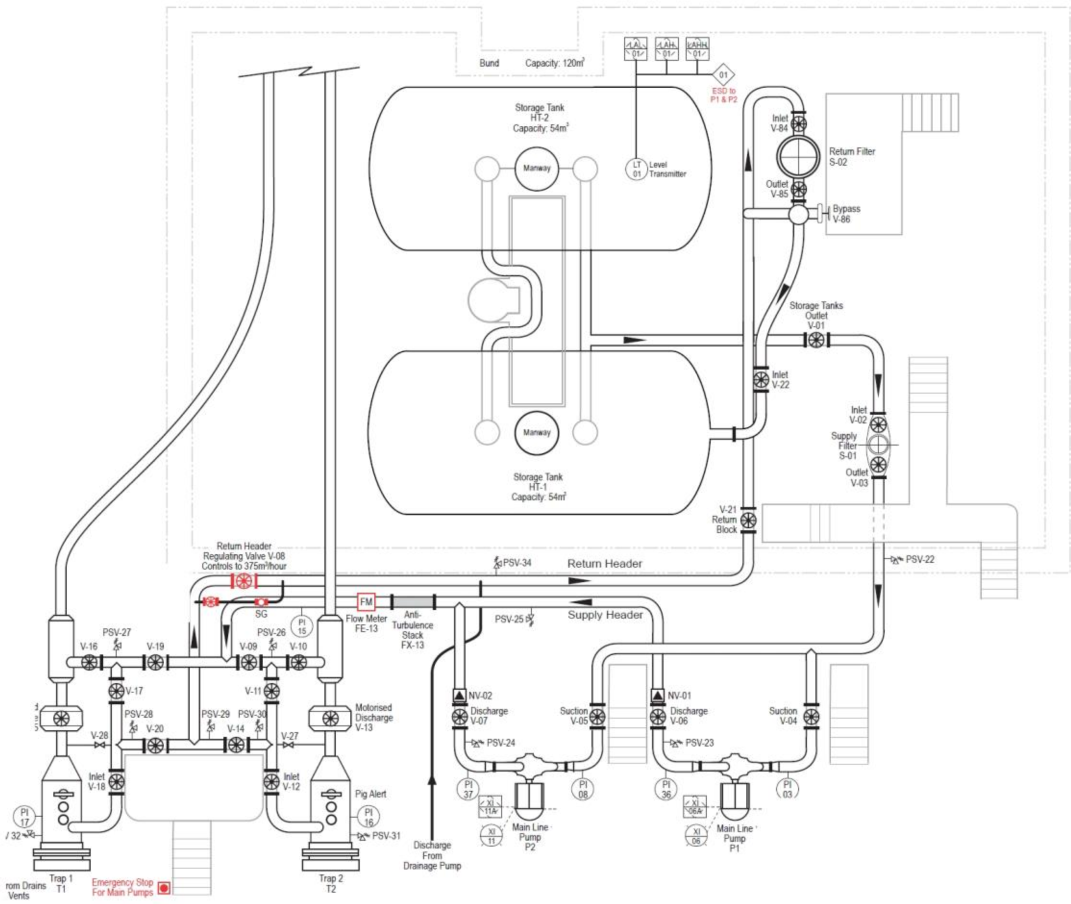

Figure 29 the launcher, receiver area

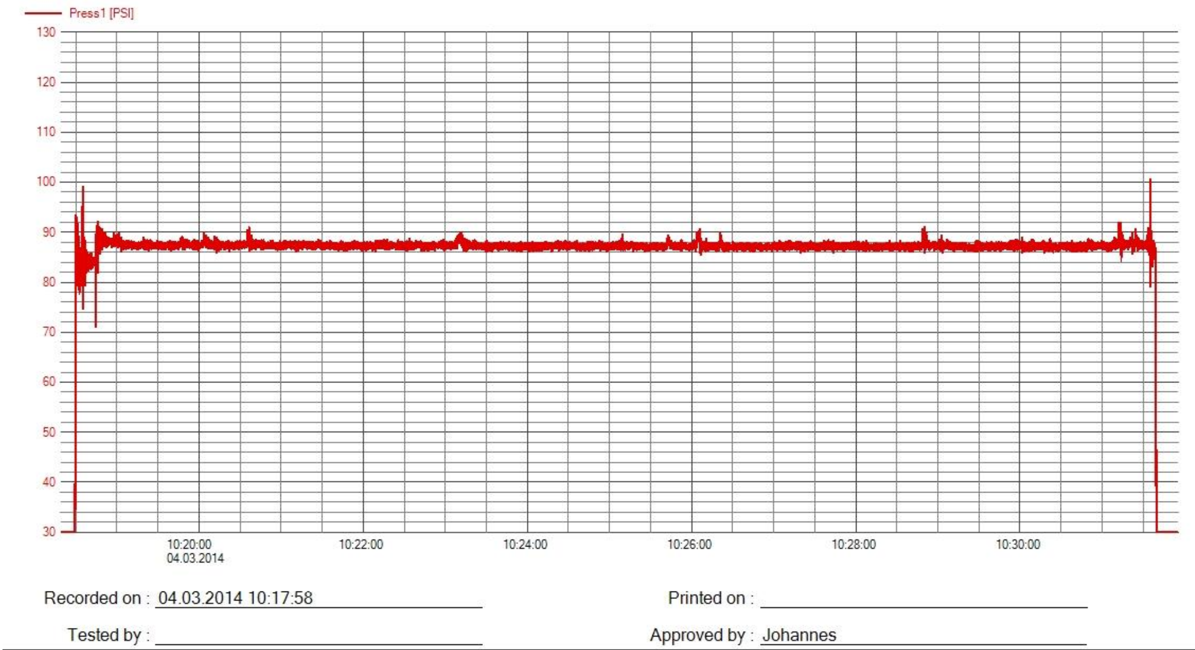

Figure 30 Run 2 04.03.2014 Samplings rate 1000 Hz Eztec TallyBook, signal from launch to arrival

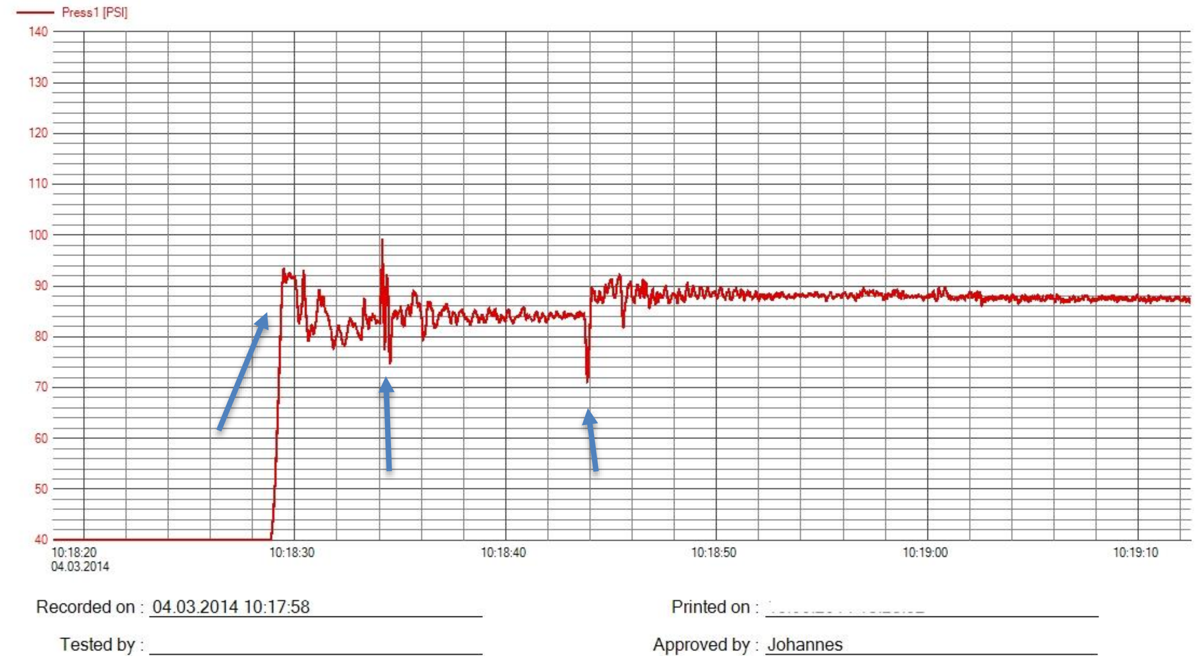

Figure 31 Run 2 04.03.2014 Signal at pig launcher, and passing the pipeline bridge

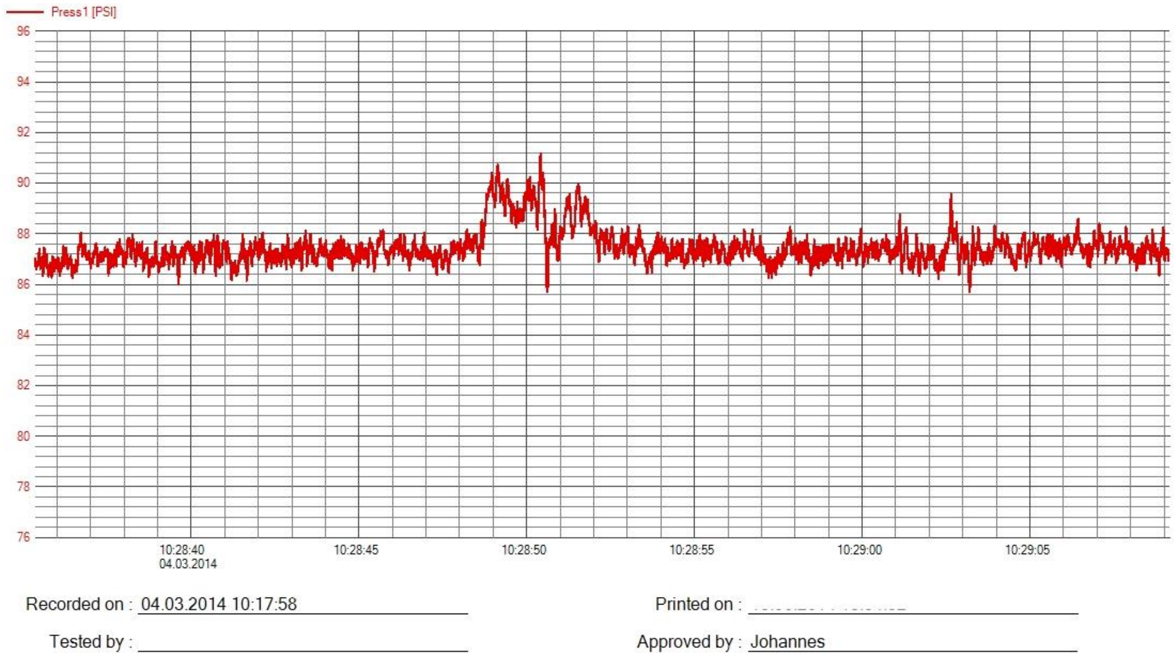

Figure 32 Run 2 04.03.2014 ***BiDi pig,*** *Signal after 780m or 618 sec run time*

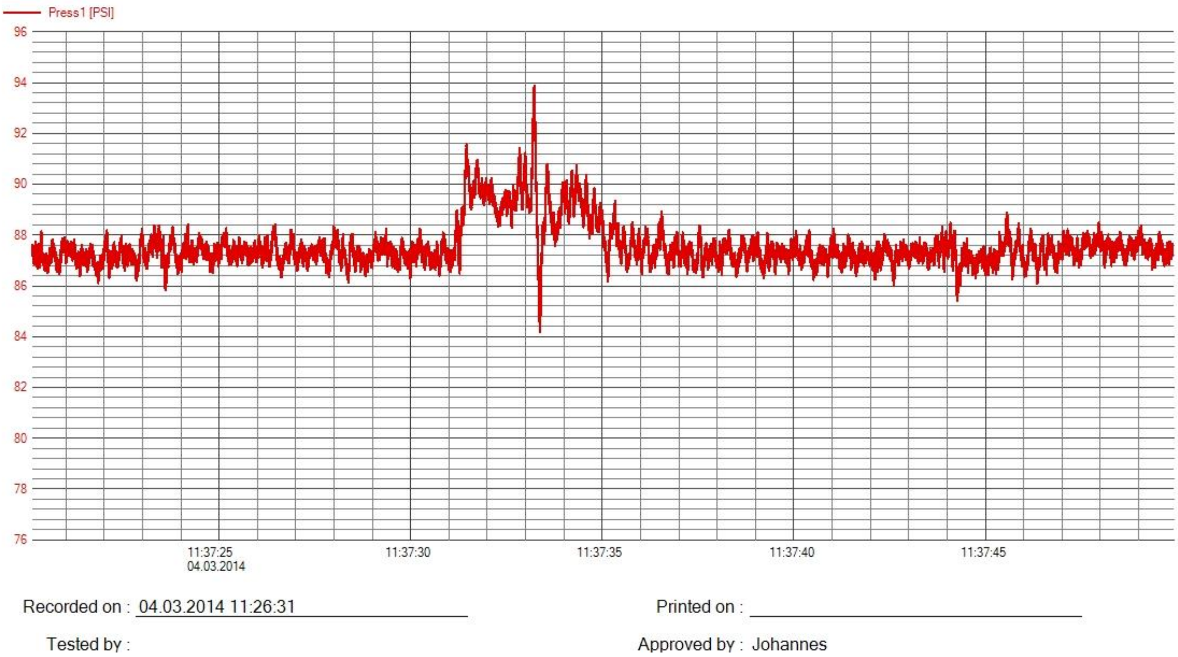

Figure 33 Run 5 04.03.2014 ***BiDi brush pig****, Signal at 780m or about 618 sec run time*

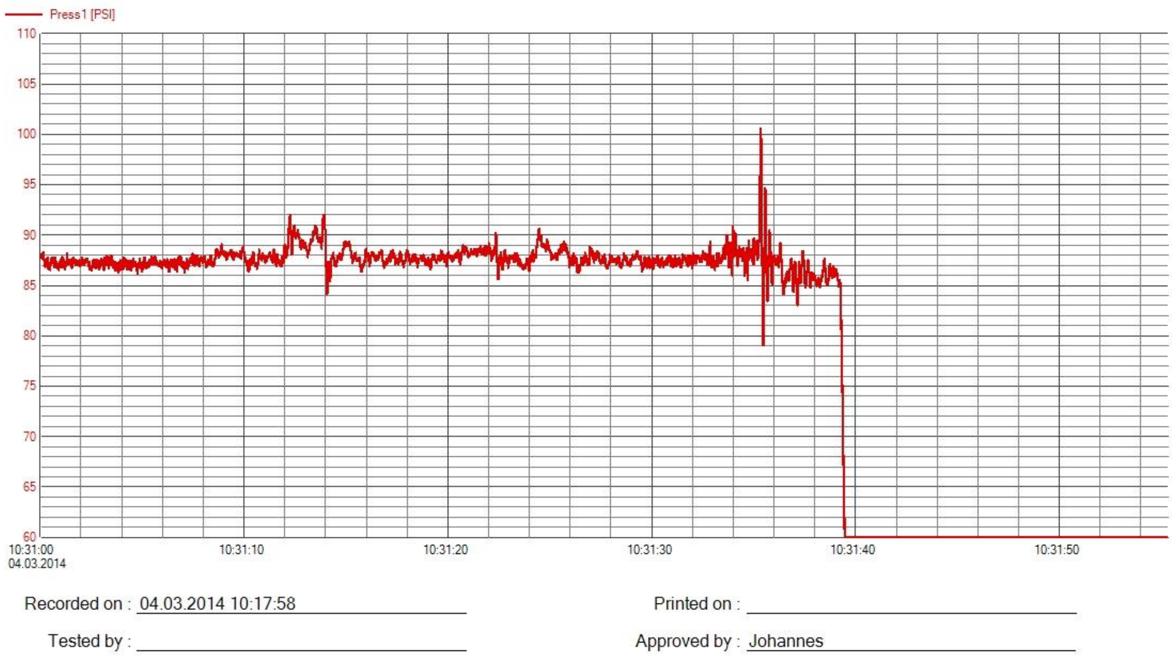

Figure 34 Run 2 04.03.2014 Signal at pig receiver

5. Optimising pipeline maintenance - discussion

In order to review and propose an update to the maintenance programme and present options that could optimise the maintenance, a few premises are introduced.

- The qualification of the new technology is at a satisfactory level according to the DNV-RP-A203 (Veritas, 2001).
- The method fulfils all demands and requirements concerning an operational verification trial.

The results obtained from the case studies enable these assumptions to be set. The first case study verified the concept of observing internal diameter change by monitoring the pressure signature on the pig launcher. Based on these results, the second subsequent case study was performed at a large-scale test facility with a longer pipeline. As shown in chapter 0, it is possible to identify a number of features based on the pressure signature recorded on the pig launcher during the pigging operation.

Assuming the technology qualification is accepted, the following section will discuss if the presented method and technology can be applied to optimise the pipeline maintenance programme.

5.1. Updating inspection plan

The initial inspection plan is based on various risk assessments, best practice, previous experience and documentation produced in the pipeline design phases. Updating the inspection plan is done annually and periodically.

The periodic update is preformed every 5-7 years and is a detailed re-assessment of the entire system. This is done because the threat picture and their probabilities may have changed since the last time this was performed. A change in threat that will influence the pigging activities could be changes in the crude oil components over time changes. The water content may have gradually increased and the risk for an internal corrosion threat has increased accordingly. If such a change is detected, the initial management plan requires the periodic update to remap the entire pipeline system and all system threats.

An annual update is done to incorporate the knowledge and information gained over the same period. The annual update also evaluates new methods and technologies within condition monitoring and inspection. In this respect, the presented method and technology if implemented could maybe provide operators with pipeline condition data from the utility pigging, previously not obtained.

Finally, there is the event triggered maintenance update, reviewed and discussed in Figure 5. Here, an unacceptable and unforeseen internal pipeline corrosion triggered an investigation. The outcome of this investigation was a changed and updated inspection plan, the launch of an extensive cleaning and internal inspection programme.

5.2. Optimising maintenance programme

After reviewing the management plan with regards to pipeline inspection activities, there are areas that could benefit from utilising the presented method and technology. Based on the results found in the case study, the following are areas where the method and technology could yield improvements and therefore could optimise the current maintenance programme:

A major activity in pipeline maintenance is pipeline cleaning using utility cleaning pigs. The pigging frequency is performed on a time interval dependent on the pig type and purpose of pigging. This is all done according to the initial inspection plans. This maintenance policy or strategy is known as a preventive maintenance. Incorporation of presented technology during the utility pigging can yield information on the pipeline ID and ID changes. A cause of ID changes could be deposit conditions or the accumulation of wax accumulation. This information can assist in adjusting and predicting when to perform further maintenance activities, such as chemical batching or aggressive pigging. This type of maintenance strategy is referred to as predictive maintenance often-called condition based maintenance (CBM). “Compared to the other maintenance policies, CBM is often more effective in avoiding over- or under-maintenance” (Guo et al., 2014,p.249).

There are also considerable disadvantages in having an incorrect pigging frequency. If the pipeline is not cleaned with pigs at a sufficient rate, there is a higher possibility that the wax accumulation rate will increase. This will also be the case if the pipeline does not meet the required cleanness prior to an ILI operation, which could result in the collection of low quality data. Over-pigging also has disadvantages. The increase in resource demand on personnel is one of them. A pigging operation usually has an impact on production due to some interference with normal operation. Each time a pigging run is preformed there is a risk that the pig could get “stuck” in the pipeline. Subsequently increasing the number of pigging runs correlates to an increase in the probability of getting a “stuck” pig. Another disadvantage of over-pigging is unnecessary wear on the pipe wall, pigs and pigging equipment.

The real time monitoring of the utility pig can determine the average pig velocity, which again can be used to calculate and predict the pig arrival time. This information can be used when planning the facility’s daily activities and pig retrieval. An up-to-date estimated time of arrival, can possibly reduce the overall time spent on retrieving a utility pig from the pig receiver.

6. Discussion of results from case studies

A primary objective was to introduce and demonstrate a method and technology for use during conventional pipeline pigging that could acquire information regarding the pipeline condition. The outcome of the case studies indicates that it is possible to observe changes in the internal pipeline diameter, when recording the pressure on the pig launcher during a pigging operation. It also shows that it is possible to identify and locate features within the pipeline.

Recording and analysing the pressure data acquired during a conventional pigging operation, can yield information regarding the internal condition of the pipeline. In order to evaluate the internal condition, the pressure signature of the pipeline needs to be determined. During the analysis, the pipeline components are located, these are found due to their individual pressure signal. Other important parameters that influence the signal is found to be the pig characteristic, pigging velocity and production related parameters as flow rate, pressure. The latter parameters are considered variable. Each component and known feature is identified and located on the pipeline pressure signature. This process creates a baseline signature for this pipeline. Further, each additional pig run operation generates a new pressure signature. Comparing the pressure signatures over several runs, a trend can be found. The ΔP between the signals may indicate a change in the pipeline environment.

To increase the accuracy and trustworthiness of the data collected, isometric pipeline drawings and operational parameters are two significant sources of information that should be acquired and reviewed. The quantification of the features concerning their change in pipeline ID is possible if the pigs' configurations and characteristics are known and evaluated. To utilise this quantification method some recommendations, criteria, and acceptance levels need to be established.

In the case studies, simplification of data can be a source of error; in Figure 21 the data showed two indications within *pipe spool VI.* An external visual inspection on the spool concluded that the indications observed in the data were one girth weld on each identified location. Using this information, the author calculated and predicted the length between the disk sets of the pig, Table 6. The indication (I1) length on both the presented pig runs was the same and the calculated result corresponded to the actual length between the disk sets. Indication (I2) in Figure 21 was also analysed and the same length calculation was performed. This did not correspond to the actual length of the pig disks, and a closer assessment of indication (I2) was done. The author acquired further information concerning *pipe spool VI* and the conclusion was that indication (I2) is a girth weld with defects. The weld defects are intentionally made and are used as a "blind test" for a weld inspection tool being developed by the authors company. Further information on the actual weld defects is at this point not obtainable. The concluding remark is that the data need to be evaluated "as is"; over simplification and assumptions may in some cases lead to an incorrect conclusion with regards to the pipeline condition.

The case study in Bergen has also indicated that this method could possibly observe the loss of containment if the pig passes a section were this is a failure mode, ref section 4.1.4

The method has been evaluated and tested in a simple non-complex pipeline in comparison to actual pipeline systems. The complexity, meaning the amount of components, length, and possible unknown pipeline configuration, are new challenges the method needs to evaluate. This will take time and it is therefore important to try to keep the complexity as low as possible, especially during the technical qualification and the subsequent verification tests.

Protruding girth welds are observed in the first case study, and discussed in connection with information for Table 4. The results show that there was a correlation between the pigging force and the change in ID. This was used to calculate and find the relation between the ID change and force required needed to overcome the section. To increase reliability the establishment of acceptance levels concerning the pig sizes and the forces is an important criteria. Linearity was an assumption for the calculations, to verify if this is valid and increase the accuracy of the calculations further research need to be done.

7. Future work

The master's thesis results are based on case studies with certain limitations as previously discussed. Below are a series of suggestions for future work. Included are also ideas for developing the potential of the method and technology.

- Test in actual pipelines

A major part of the future work is the verification of the technology when expanding to longer pipelines, as well as pipelines located subsea at depths. Length and elevation are parameters that directly influence the data collected topside. In longer pipelines, parameters that have been insignificant in the case studies exercise an obvious effect due to increased length and changes in elevation.

- Database of pipeline components

A suggestion for future work is to generate and develop a database that contains pressure signals of recognised components and features. Archiving each component signal acquired for each particular component may in the future simplify an identification process. Considering that, some features and components are likely to occur in several pipeline systems. The creation of a database with different features and their pressure signal may simplify the future analyse and detectability of the system.

- Development of real-time software

A suggestion concerning the logging equipment is the development of a real time software that compares the current ongoing pigging operation with prior pressure recordings. A fully automated system would require less intervention and reduce the manning requirements. Alarms could be set on different conditional parameters and unforeseen incidents. Remote controlling the system can yield options for online configuration and assistance by the system vendor, as well as offsite data transferal for further analysis and data validation.

- Adaption to multiphase fluid

In addition, a future work option is to evaluate the possibility for adapting the system to be able to monitor the pig operation on a multiphase pipeline system. In the thesis, the pipeline fluid has been a single phase liquid. The single phase liquid was chosen based on its simplicity compared to a multiphase. The theory for multiphase is known but is more complex, and more parameters need to be taken into consideration. The advantages of adapting the system to multiphase fluids are indisputable, considering that many pipeline systems have a multiphase production.

8. Conclusion

This master's thesis has investigated a new method of detecting internal diameter change in a pipeline. Relevant theory has been presented and the results from the two case studies show that the method is feasible. To fully investigate the potential of the method, some future work suggestions have been proposed.

Incorporating the technology as conditional monitoring used during the pigging operations gives the possibility of changing the maintenance policy from a preventive to a predictive maintenance strategy. One benefit is finding the appropriate pigging frequency, which subsequently has several advantages such as less wear, and increased pigging efficiency.

The master's thesis gives insight to the idea that pipelines conditions can be monitored without interfering with normal pigging operation. Proposing a method for optimisation of pipeline maintenance has shown promising results in the case studies. Further development and adaptions are required prior to monitoring an actual operation. The results are positive, and show that by recording and analysing data from a pigging operation, ID change in the pipeline was detected.

Using the deposit profiling technology shows promising results in optimising the pipeline maintenance programme. To further evaluate the technology and its potential, it needs to be utilised during an actual operation, which probably will lead to new challenges.

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10. Appendix

10.1. Terms and definition

Stuck pig

A pig that do not move within the pipeline, reasons could be, full bypass over the pig. Or a full blockage resulting in a no-flow environment.

All terms and definition below are selected and then quoted from The PPSA (1995)

Cleaning pig

"A utility pig that uses cups, scrapers, or brushes, to remove dirt, rust, mill scale, or other foreign matter from the pipeline. Cleaning pigs are run to increase the operating efficiency of a pipeline or to facilitate inspection of the pipeline."

In-line inspection (ILI)

"The inspection of a pipeline from the interior of the pipe using an in-line inspection tool."

In-line inspection tool

"The device or vehicle, also known as an 'intelligent' or 'smart' (ILI tool) pig, that uses a non-destructive testing technique to inspect the wall of a pipe. An in-line inspection tool is one type of instrumented tool."

Instrumented pig

"A vehicle or device used for internal inspection of a pipe, which contains sensors, electronics, and recording or output functions integral to the system. Instrumented pigs are divided into two types:

(1) configuration pigs, which measure the pipeline geometry or the conditions of the inside surface of the pipe; and

(2) in-line inspection tools that use non-destructive testing techniques to inspect the wall of the pipe for corrosion, cracks, or other types of anomalies."

(Pig) - Launcher

"A pipeline facility used for inserting a pig into a pressurized pipeline."

Metal loss

"Any of a number of types of anomalies in pipe in which metal has been removed from the pipe surface, usually due to corrosion or gouging."

Pig

"A generic term signifying any independent, self-contained device, tool, or vehicle, that moves through the interior of the pipeline for purposes of inspecting, dimensioning, or cleaning. "

(Pig) - Receiver

"A pipeline facility used for removing a pig from a pressurized pipeline."

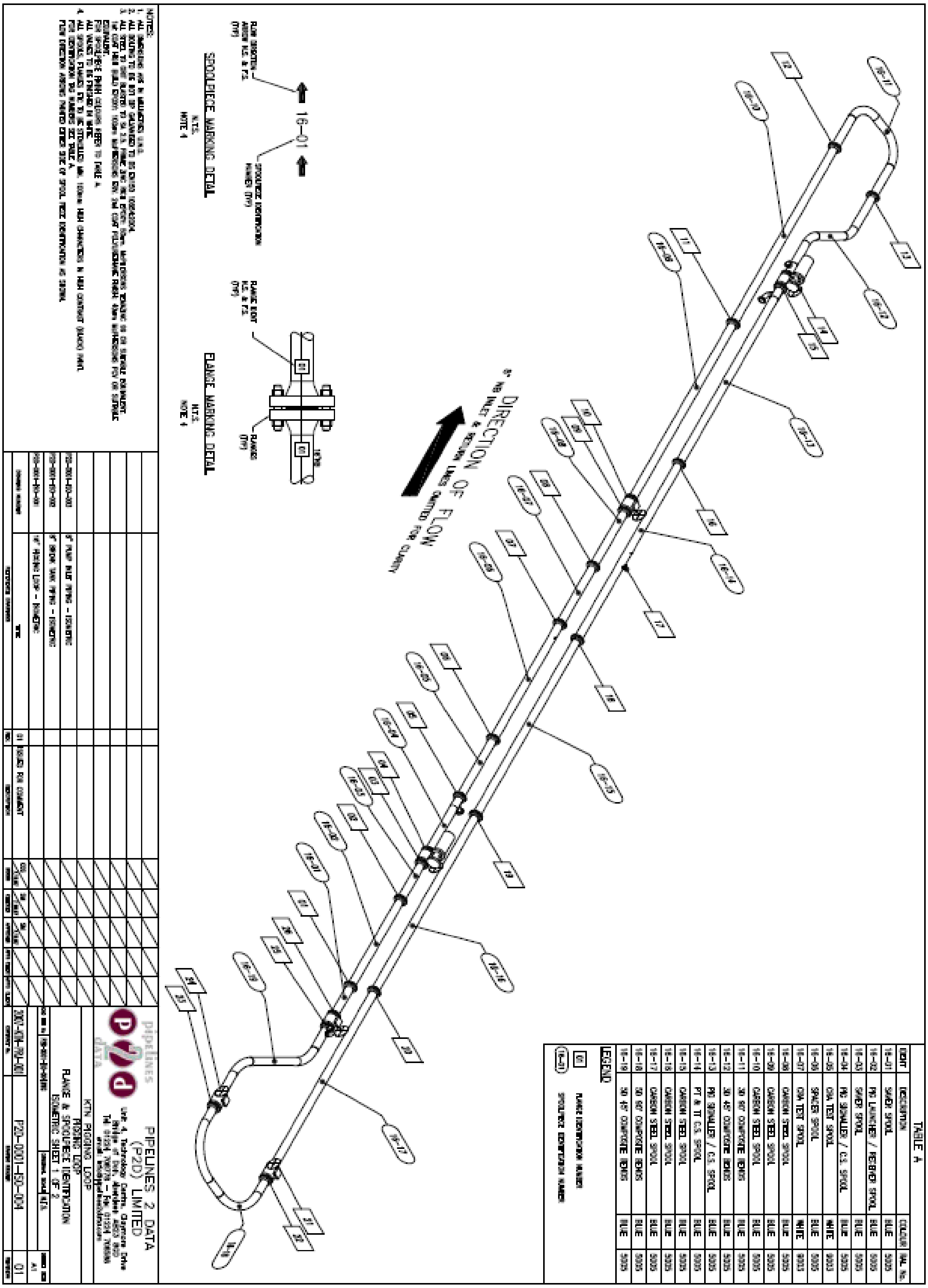
Trap

"Pipeline facility for launching and receiving tools and pigs."

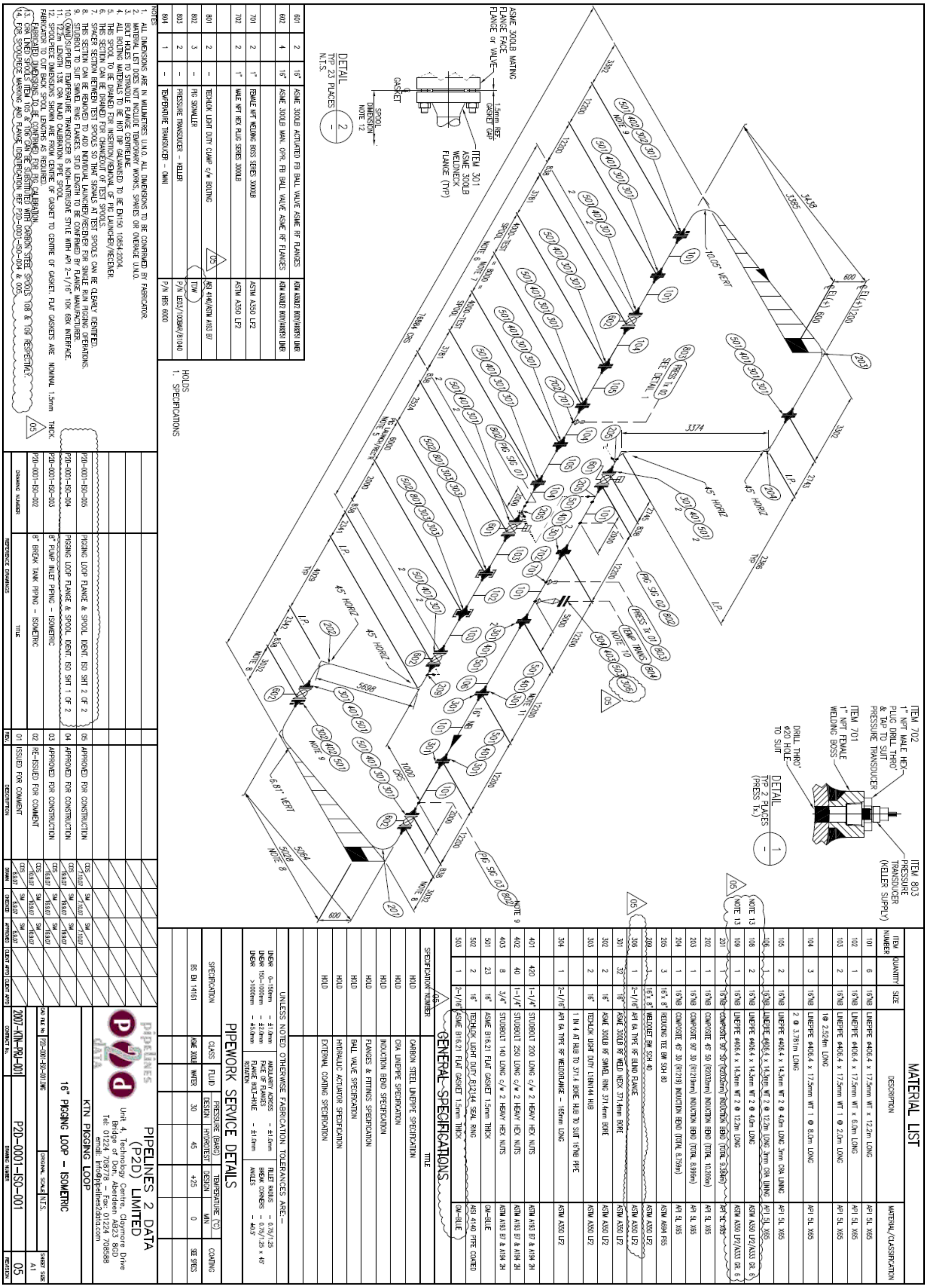
Utility pig

"Pig that performs relatively-simple mechanical functions, such as cleaning the pipeline. "

10.2. Isometric drawing KTN test loop 1/2



10.3. Isometric drawings KTN test loop 2/2



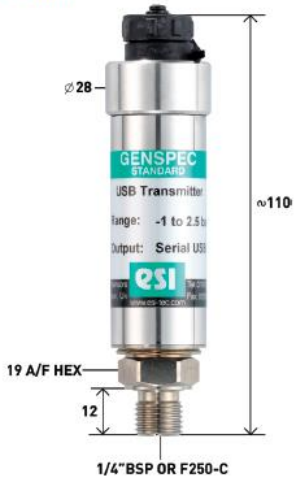
10.4. ESI- tec

PRESSURE RANGES

-1 to 2.5bar through to 4000 bar, see table below for list of all standard pressure ranges.

Range (bar)	Order Code	Range (bar)	Order Code
-1-2.5	02.5	0-2000	2000
0-16	0016	0-3000	3000
0-100	0100	0-4000	4000
0-400	0400		
0-1500	1500		

DIMENSIONS (in mm)



ORDERING INFORMATION

	GS4200	-	USB xxxx	xx
Model	GS4200			
Electrical Connector/Option			USB	
Pressure Range - Bar			xxxx	
Process Connection				xx

ELECTRICAL CONNECTION/OPTION	Order Code
2 metre A to USB mini B lead	GS4200-USB
PROCESS CONNECTION	**Order Code**
1/4" BSP male thread	AB
1/4" NPT male thread	AM
9/16" x 18 UNF-2B F250C Autoclave (2000bar +)	DE
EXAMPLE	**Order Code**
2 metre A to USB mini B lead	GS4200-USB
Pressure range 0-100barg	0100
Pressure connection 1/4" BSP male	AB
Correct Part Number	GS4200-USB0100AB
For options not listed contact sales team	

DISCLAIMER:
ESI Technology Ltd operates a policy of continuous product development. We reserve the right to change specification without prior notice. All products manufactured by ESI Technology Ltd are calibrated using precision calibration equipment with traceability to international standards.

SPECIFICATION

PRESSURE REFERENCE

Gauge (default). Absolute reference input by user.

OVERPRESSURE

Pressure can exceed rated range by the multiple shown below with no damage or change in calibration above ±0.5%FS.
2x for ranges up to 400bar
1.5x for 1500bar
1.5x for 2000bar
1.25x for 4000bar

OUTPUT SIGNAL

USB 1.1 and USB 2.0 full speed connection.

RECALIBRATION

Fully configured and re-calibrated via PC software, including pressure unit selection linearity and temperature compensation adjustment.

SUPPLY VOLTAGE

5Vdc via USB bus.

ACCURACY (NON LINEARITY, HYSTERESIS & REPEATABILITY)

±0.15%FS Typical Max. Best fit straight line.

PRESSURE MEDIA

All fluids compatible with titanium alloy.

RESOLUTION

Up to 21 bit pressure measurement.

OPERATING TEMPERATURE RANGE

Ambient: -20°C to +85°C
Media: -50°C to +125°C
Storage: +5°C to +40°C

ELECTROMAGNETIC CAPABILITY

Certification: CE marked

PRESSURE CONNECTION

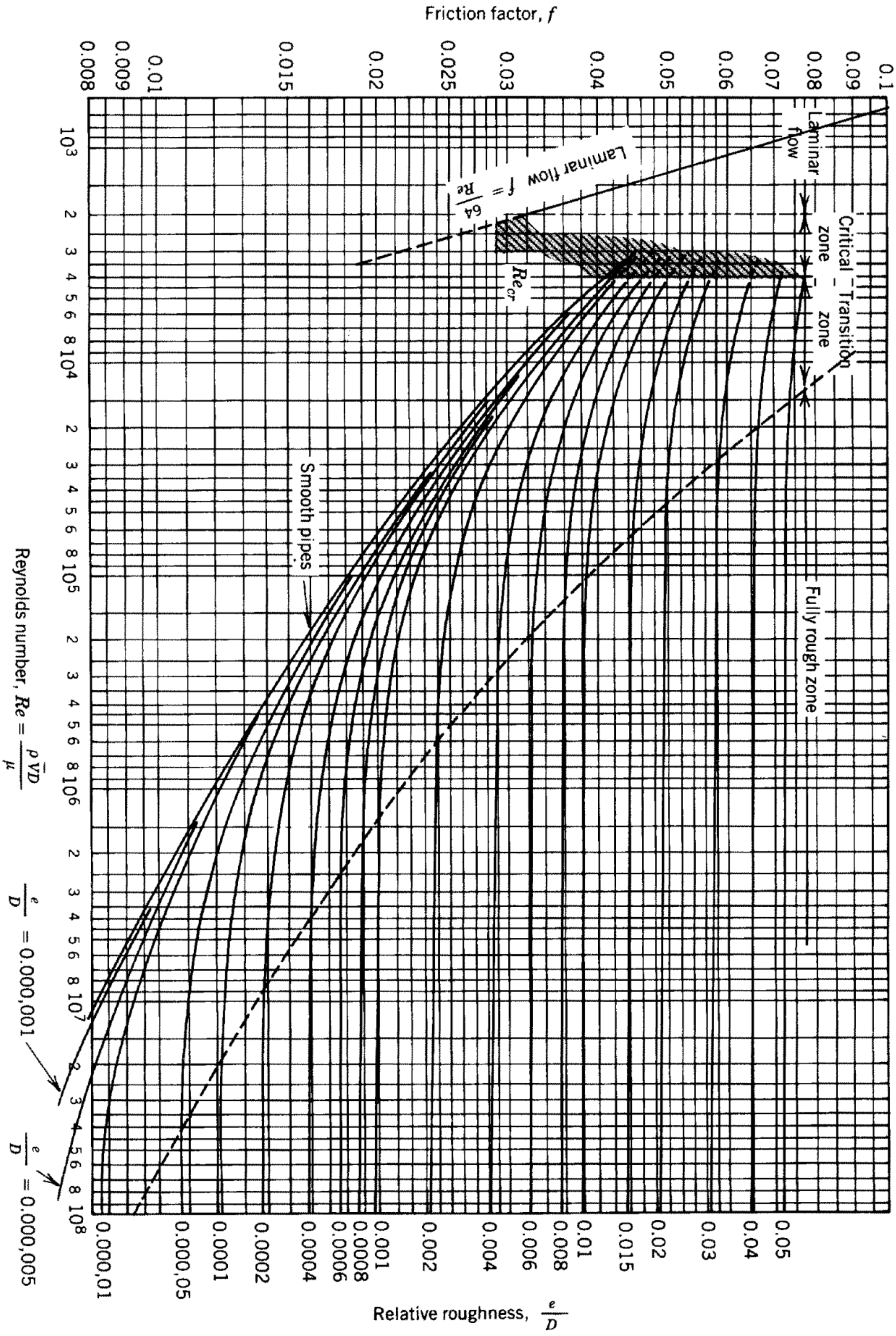
1/4" BSP male or F250-C (Autoclave)

ELECTRICAL CONNECTION

Mating to USB Mini B socket for cable connection to PC. Supplied with 2m USB lead rated to IP68 as standard.

t. +44(0)1978 262 255 e. sales@esi-tec.com www.esi-tec.com

10.5. Moody diagram



10.6. Purpose made code on the Arduino board

```
 // Case study Bergen,  DAC, 1000HZ sampling, by Johannes Dahl



int outputValue = 0;
// the setup routine runs once when you press reset:
void setup() {
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600);
}

// the loop routine runs over and over again forever:
void loop() {
  // read the input on analog pin 0:
  int sensorValue = analogRead(A0);
  // map it to the range of the analog out:
  outputValue = map(sensorValue, 0, 1023, 0, 5000);
    // print the results to the serial monitor:
 // Serial.print("sensor = " );
  Serial.print(sensorValue);
 Serial.print("\t ");
 Serial.println(outputValue);
  delay(10);        // delay in between reads for stability
}
```

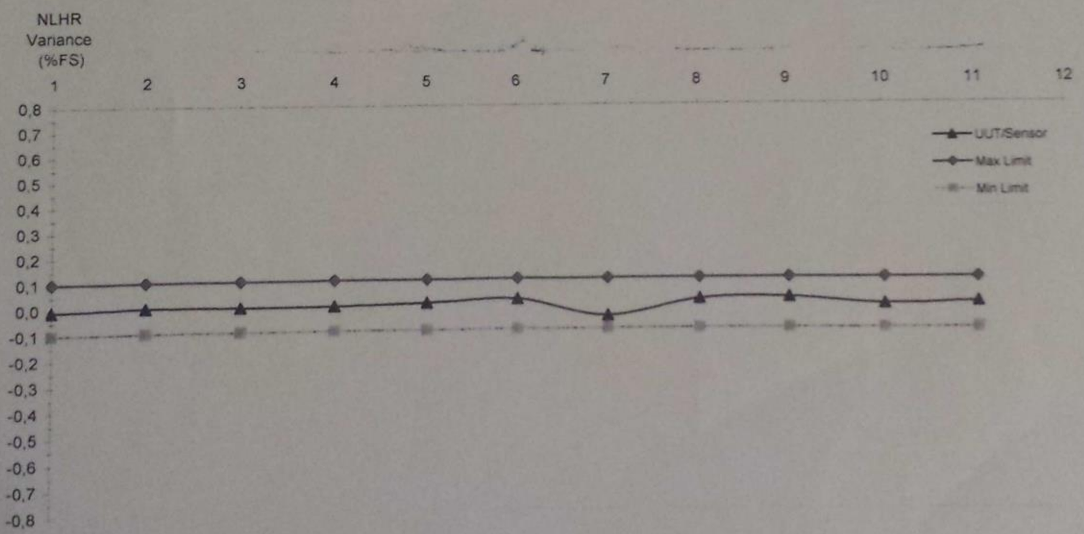
10.7. Calibration certificates

Calibration Certificate

Pump Tech
Products and services within pumps and hydraulics

Type:	GS4200 pressure transmitter	Manufacture date:	29.05.2013
Serial No.:	142725	Calibration date:	22.01.2014
Range:	0..... 250,00 bar g	Calibration temperature:	20,9 °C
Output:	0 250 bar g	NLHR Tolerance:	± 0,10 %FS

Nominal Value (bar g)	Actual Value (bar g) from Pressure Reference	Unit Under Test Reading (bar g)	NLHR (%FS) (1)	Result
0,0	0,000	-0,017	-0,0081	ok
50,0	50,000	49,962	0,0003	ok
100,0	100,000	99,912	-0,0026	ok
150,0	150,000	149,871	-0,0023	ok
200,0	200,000	199,853	0,0078	ok
250,0	250,000	249,839	0,0188	ok
200,0	200,000	199,712	-0,0487	ok
150,0	150,000	149,915	0,0154	ok
100,0	100,000	99,970	0,0206	ok
50,0	50,000	49,947	-0,0058	ok
0,0	0,000	0,015	0,0046	ok
			Overall Result:	**PASS**



All calibration equipment used has been calibrated and certified by an external UKAS accredited laboratory or has been verified against equipment calibrated and certified by a UKAS accredited laboratory

Pressure reference:	Const273 700 Bar
Serial/Plant No.:	27313020186

Inspected by

22.01.2014
Date

Daniel Olsen

Note (1) NLRH is non-linearity, hysteresis and repeatability calculated by best fit straight line method

Rev. 1.0

EZTEK

REGISTERED IN SCOTLAND NR. 146534
REGISTRATION ADDRESS:
NEWHOUSE, TYREBAGGER,
CLINTERTY, KINELLAR,
ABERDEEN AB21 0TT

Calibration Certificate 14-EZCC0263

Client	Eztek	Model:	EZ1022
Location	Blackburn	Serial No.:	1098
Date	28th February 2014	Customer ref:	n/a

The above mentioned pressure logger has been calibrated according to work instruction WI 057 to UKAS national and international standards using the following calibration device;

Manufacturer	Druck
Model	DP104
Serial No.	2876757
Last Cal Date	22/01/2014
Accuracy	+/-0.01%FS
UKAS Cert No.	07115

UKAS Certificate traceable to Accredited Laboratory 0123

Channel 1: Sensor HP1003 Serial number: 122468 (0 to 1,000 psi)

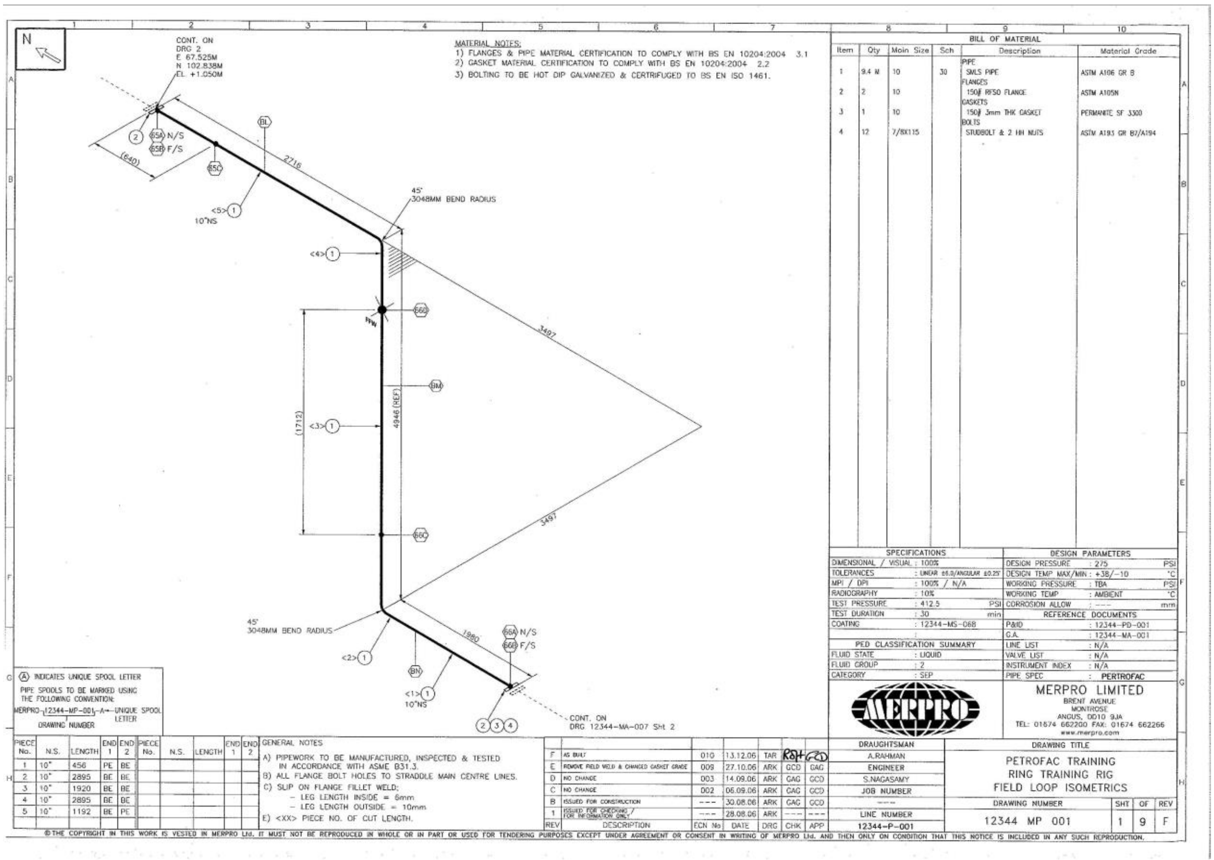
Calibration spot check results:

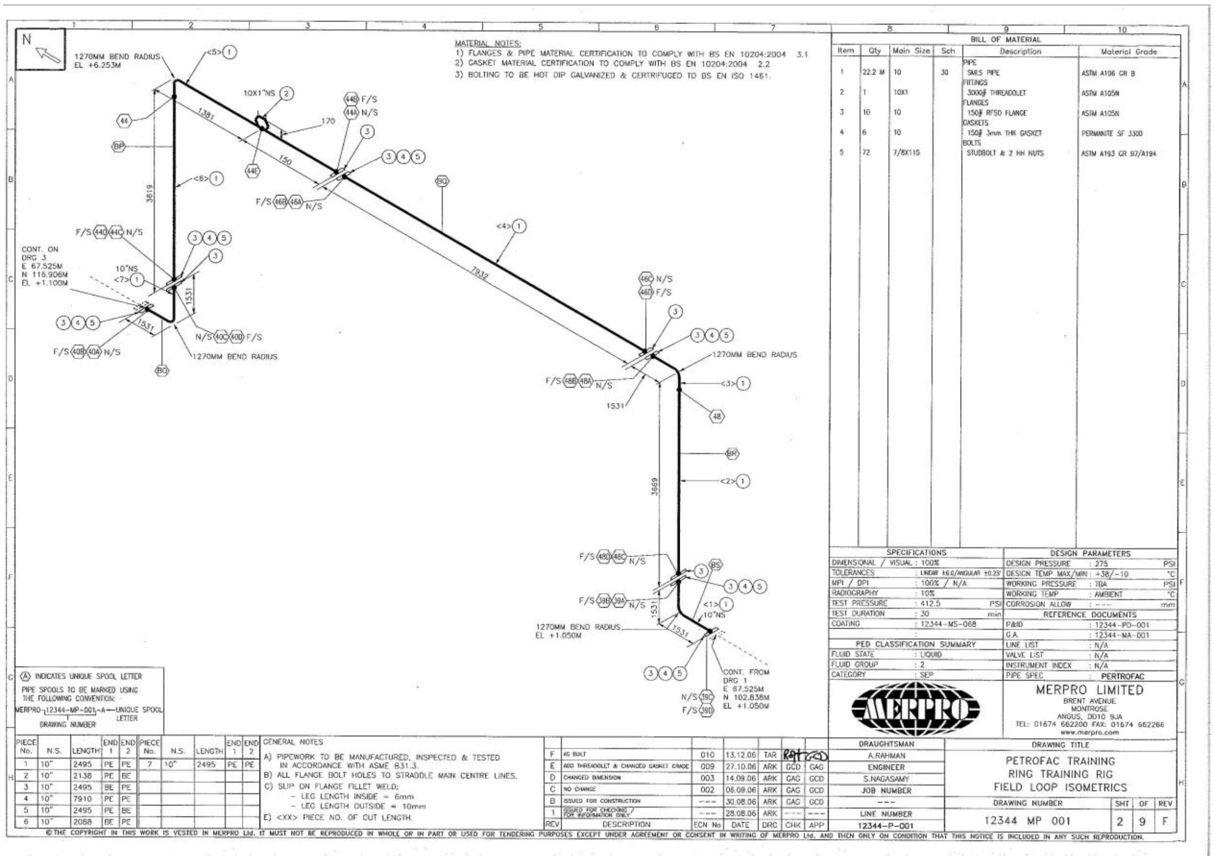
Applied Pressure (PSI)	Read Pressure (PSI)	Error (PSI)	Full Scale Error (%)
0	0	0	-
250	250.2	0.2	0.08
500	500.5	0.5	0.10
750	750.7	0.7	0.09
1000	1001	1	0.10

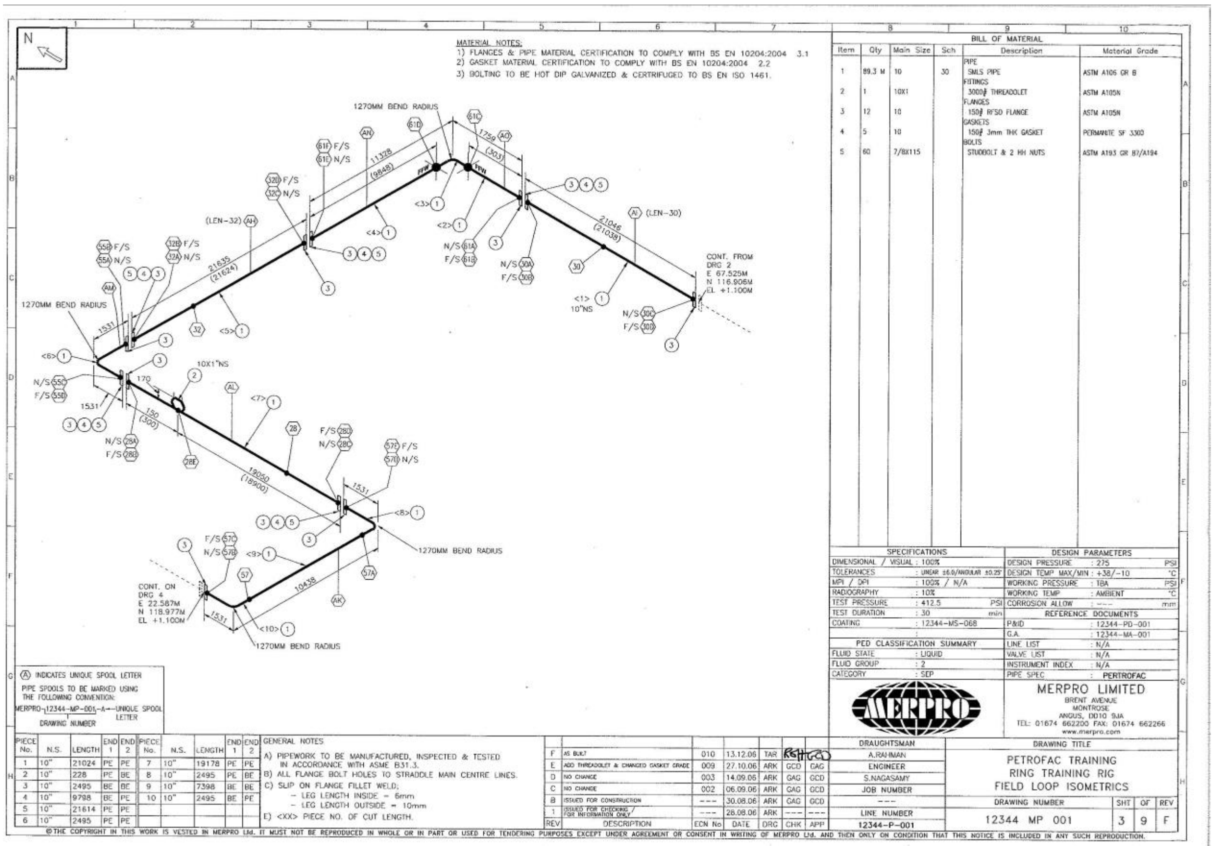
Latest Calibration Coefficients

Calibration Point #	Pressure Set Value (PSI)	Raw Count
1	0	2554848826
2	1000	4203190700

10.8. Isometric drawings Montrose 1-9






MATERIAL NOTES:
1) FLANGES & PIPE MATERIAL CERTIFICATION TO COMPLY WITH BS EN 10204:2004 3.1
2) GASKET MATERIAL CERTIFICATION TO COMPLY WITH BS EN 10204:2004 2.2
3) BOLTING TO BE HOT DIP GALVANIZED & CERTRIFUGED TO BS EN ISO 1461.
1270MM BEND RADIUS
CONT. FROM DRG 2
CONT. ON DRG 4
BILL OF MATERIAL
SPECIFICATIONS
DESIGN PARAMETERS
REFERENCE DOCUMENTS
PED CLASSIFICATION SUMMARY
GENERAL NOTES
A) PIPEWORK TO BE MANUFACTURED, INSPECTED & TESTED IN ACCORDANCE WITH ASME B31.3.
B) ALL FLANGE BOLT HOLES TO STRADDLE MAIN CENTRE LINES.
C) SLIP ON FLANGE FILLET WELD;
– LEG LENGTH INSIDE = 6mm
– LEG LENGTH OUTSIDE = 10mm
E) <XX> PIECE NO. OF CUT LENGTH.
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RING TRAINING RIG
FIELD LOOP ISOMETRICS
12344 MP 001
12344–P–001
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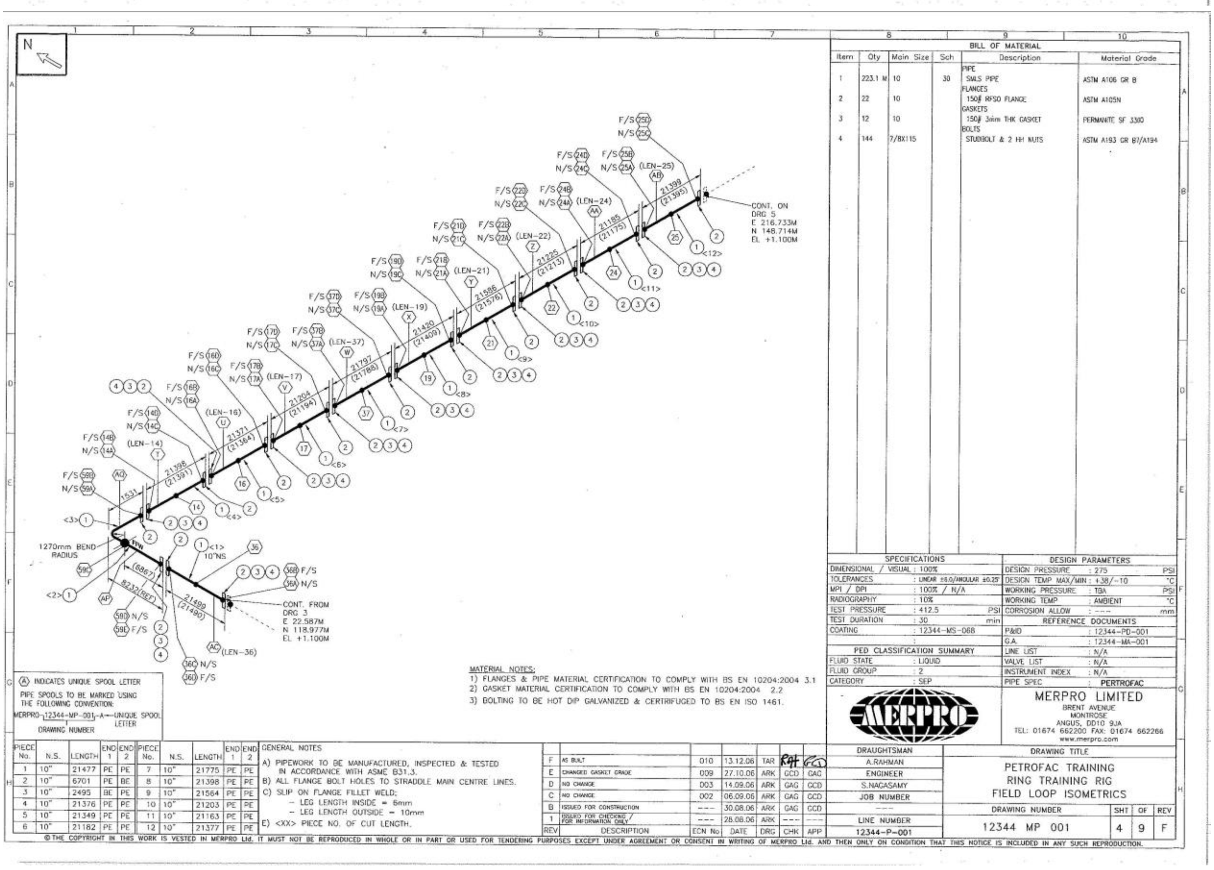
1270mm BEND RADIUS
CONT. ON DRG 5
CONT. FROM DRG 3
MATERIAL NOTES:
1) FLANGES & PIPE MATERIAL CERTIFICATION TO COMPLY WITH BS EN 10204:2004 3.1
2) GASKET MATERIAL CERTIFICATION TO COMPLY WITH BS EN 10204:2004 2.2
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BILL OF MATERIAL
SPECIFICATIONS
DESIGN PARAMETERS
REFERENCE DOCUMENTS
PED CLASSIFICATION SUMMARY
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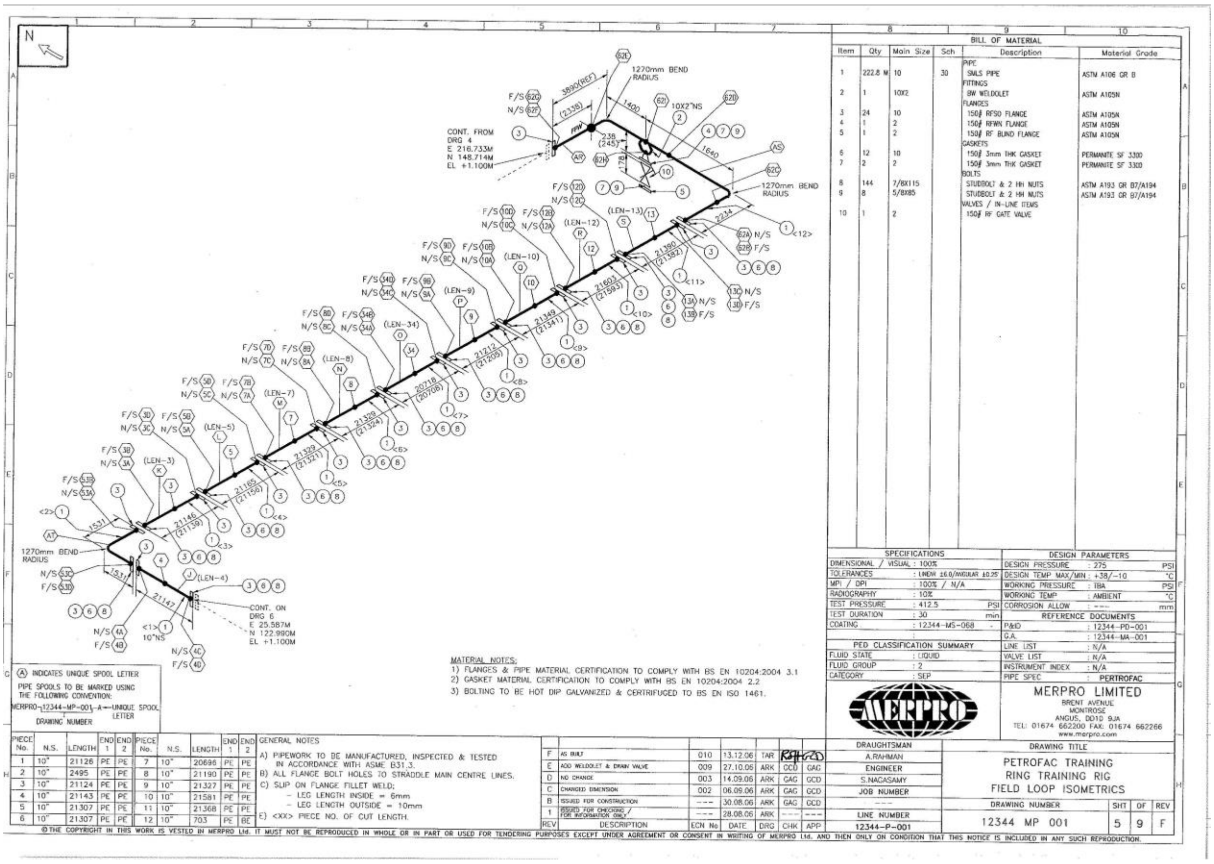
BILL OF MATERIAL
MATERIAL NOTES:
1) FLANGES & PIPE MATERIAL CERTIFICATION TO COMPLY WITH BS EN 10204:2004 3.1
2) GASKET MATERIAL CERTIFICATION TO COMPLY WITH BS EN 10204:2004 2.2
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12344 MP 001
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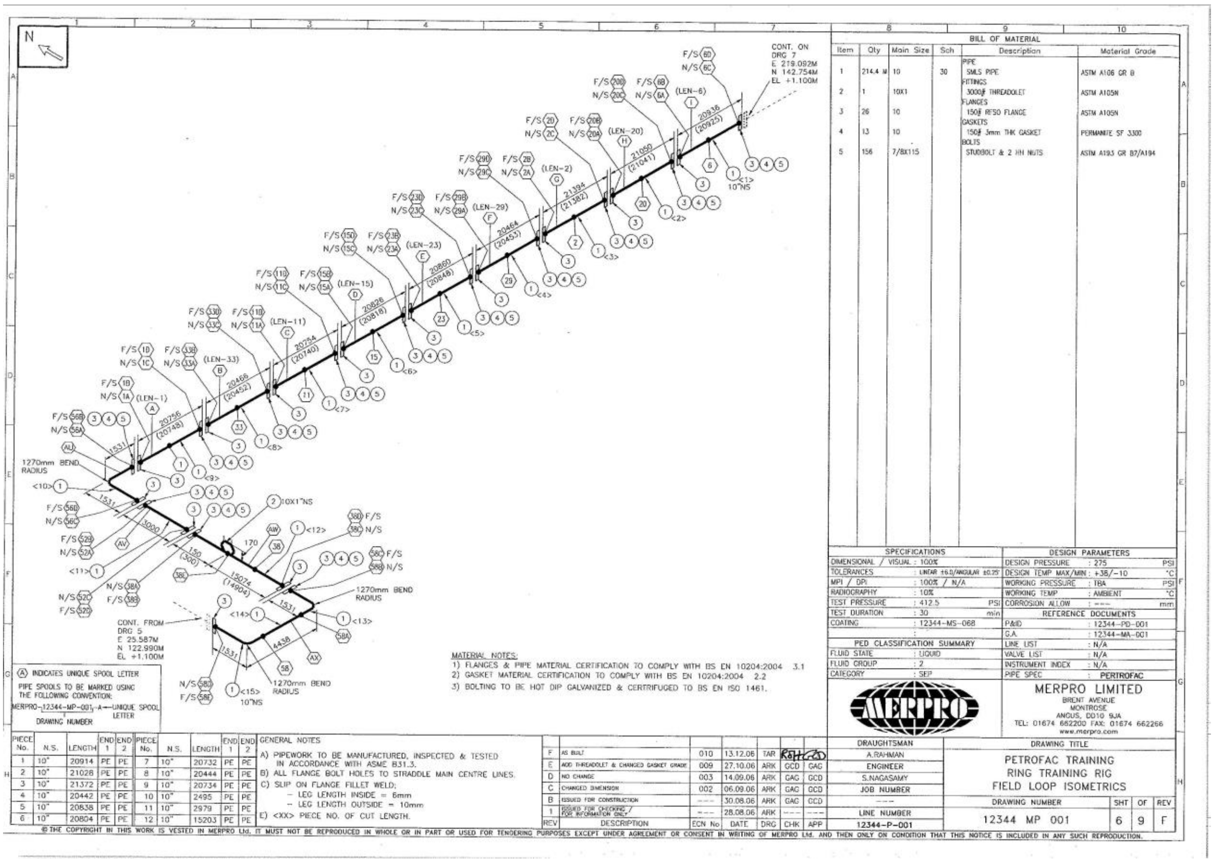
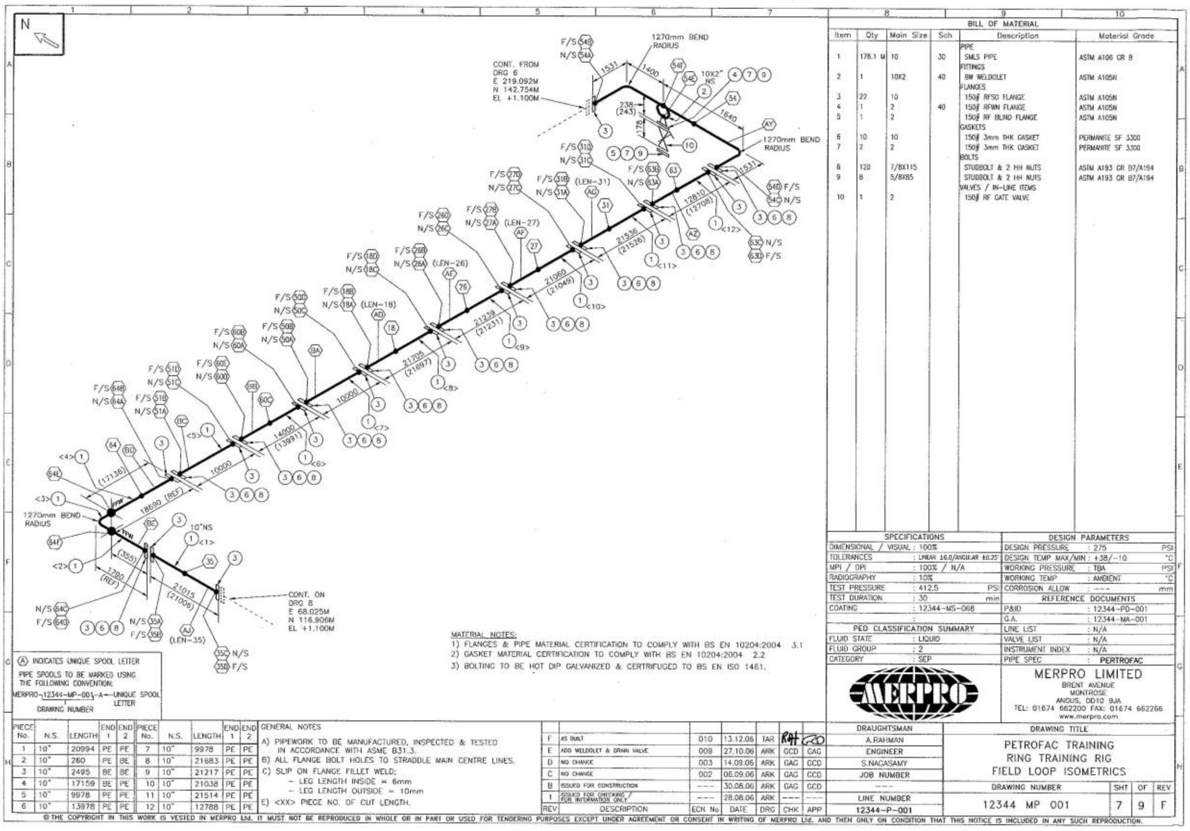

BILL OF MATERIAL
MATERIAL NOTES:
1) FLANGES & PIPE MATERIAL CERTIFICATION TO COMPLY WITH BS EN 10204:2004 3.1
2) GASKET MATERIAL CERTIFICATION TO COMPLY WITH BS EN 10204:2004 2.2
3) BOLTING TO BE HOT DIP GALVANIZED & CERTRIFUGED TO BS EN ISO 1461.
GENERAL NOTES
A) PIPEWORK TO BE MANUFACTURED, INSPECTED & TESTED IN ACCORDANCE WITH ASME B31.3.
B) ALL FLANGE BOLT HOLES TO STRADDLE MAIN CENTRE LINES.
C) SLIP ON FLANGE FILLET WELD; – LEG LENGTH INSIDE = 6mm – LEG LENGTH OUTSIDE = 10mm
E) <XX> PIECE NO. OF CUT LENGTH.
MERPRO LIMITED
PETROFAC TRAINING
RING TRAINING RIG
FIELD LOOP ISOMETRICS
12344 MP 001
12344-P-001


BILL OF MATERIAL
SPECIFICATIONS
DESIGN PARAMETERS
MATERIAL NOTES:
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MERPRO LIMITED
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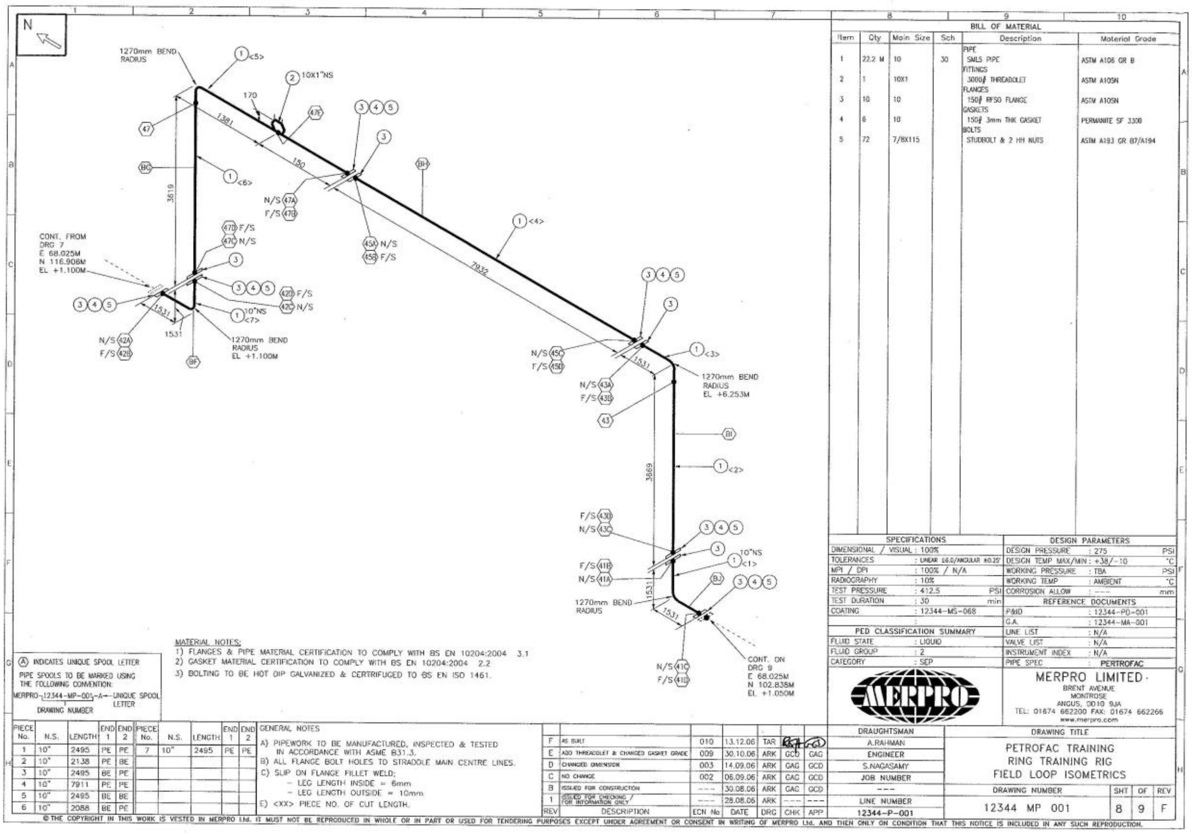
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SPECIFICATIONS
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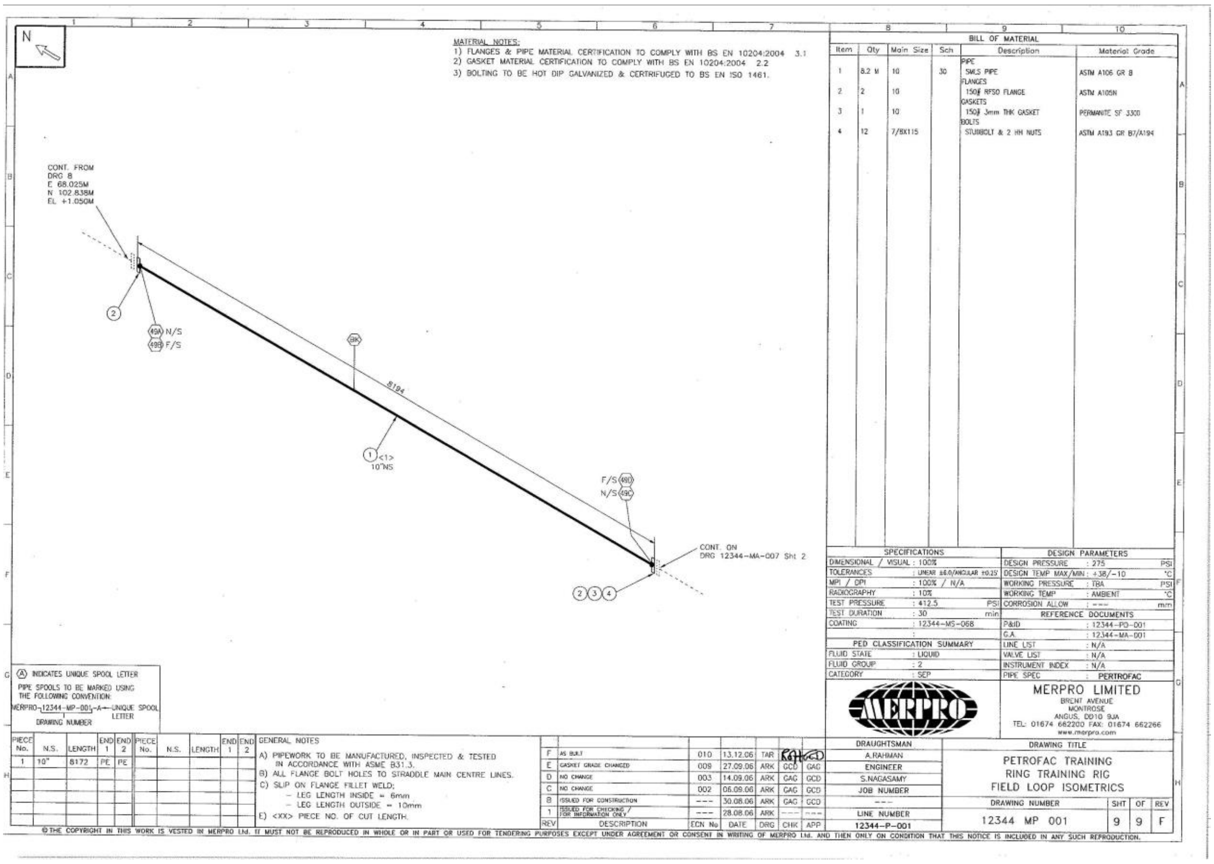
N
MATERIAL NOTES:
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2) GASKET MATERIAL CERTIFICATION TO COMPLY WITH BS EN 10204:2004 2.2
3) BOLTING TO BE HOT DIP GALVANIZED & CERTRIFUGED TO BS EN ISO 1461.
CONT. FROM DRG 8 E 68.025M N 102.838M EL +1.050M
N/S
F/S
8194
<1> 10"NS
F/S
N/S
CONT. ON DRG 12344-MA-007 Sht 2
BILL OF MATERIAL
Item | Qty | Main Size | Sch | Description | Material Grade
PIPE
1 | 8.2 M | 10 | 30 | SMLS PIPE | ASTM A106 GR B
FLANGES
2 | 2 | 10 | | 150# RFSO FLANGE | ASTM A105N
GASKETS
3 | 1 | 10 | | 150# 3mm THK GASKET | PERMANITE SF 3300
BOLTS
4 | 12 | 7/8X115 | | STUDBOLT & 2 HH NUTS | ASTM A193 GR B7/A194
SPECIFICATIONS
DIMENSIONAL / VISUAL : 100%
TOLERANCES : LINEAR ±6.0/ANGULAR ±0.25'
MPI / DPI : 100% / N/A
RADIOGRAPHY : 10%
TEST PRESSURE : 412.5 PSI
TEST DURATION : 30 min
COATING : 12344-MS-068
PED CLASSIFICATION SUMMARY
FLUID STATE : LIQUID
FLUID GROUP : 2
CATEGORY : SEP
DESIGN PARAMETERS
DESIGN PRESSURE : 275 PSI
DESIGN TEMP MAX/MIN : +38/-10 °C
WORKING PRESSURE : TBA PSI
WORKING TEMP : AMBIENT °C
CORROSION ALLOW : --- mm
REFERENCE DOCUMENTS
P&ID : 12344-PD-001
G.A. : 12344-MA-001
LINE LIST : N/A
VALVE LIST : N/A
INSTRUMENT INDEX : N/A
PIPE SPEC : PERTROFAC
MERPRO
MERPRO LIMITED
BRENT AVENUE
MONTROSE
ANGUS, DD10 9JA
TEL: 01674 662200 FAX: 01674 662266
www.merpro.com
(A) INDICATES UNIQUE SPOOL LETTER
PIPE SPOOLS TO BE MARKED USING THE FOLLOWING CONVENTION:
MERPRO-12344-MP-001-A ← UNIQUE SPOOL LETTER
DRAWING NUMBER
PIECE No. | N.S. | LENGTH | END 1 | END 2 | PIECE No. | N.S. | LENGTH | END 1 | END 2
1 | 10" | 8172 | PE | PE
GENERAL NOTES
A) PIPEWORK TO BE MANUFACTURED, INSPECTED & TESTED IN ACCORDANCE WITH ASME B31.3.
B) ALL FLANGE BOLT HOLES TO STRADDLE MAIN CENTRE LINES.
C) SLIP ON FLANGE FILLET WELD;
- LEG LENGTH INSIDE = 6mm
- LEG LENGTH OUTSIDE = 10mm
E) <XX> PIECE NO. OF CUT LENGTH.
REV | DESCRIPTION | ECN No | DATE | DRG | CHK | APP
F | AS BUILT | 010 | 13.12.06 | TAR
E | GASKET GRADE CHANGED | 009 | 27.09.06 | ARK | GCD | GAC
D | NO CHANGE | 003 | 14.09.06 | ARK | GAC | GCD
C | NO CHANGE | 002 | 06.09.06 | ARK | GAC | GCD
B | ISSUED FOR CONSTRUCTION | --- | 30.08.06 | ARK | GAC | GCD
1 | ISSUED FOR CHECKING / FOR INFORMATION ONLY | --- | 28.08.06 | ARK | --- | ---
DRAUGHTSMAN
A.RAHMAN
ENGINEER
S.NAGASAMY
JOB NUMBER

LINE NUMBER
12344-P-001
DRAWING TITLE
PETROFAC TRAINING
RING TRAINING RIG
FIELD LOOP ISOMETRICS
DRAWING NUMBER
12344 MP 001
SHT 9 OF 9 REV F
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10.9. EZtek Tallybook

To: KTN AS
Contact: Johannes Dahl
Tel:
E-mail:
From:
Date:
Pages:

Dear Johannes,

Further to your enqu ry, I wou d ke to propose as fo ows

P/N EZ1022 Zone 2 High Speed Logger (HSL)
Portable Battery Operated Logger Computer System

"Improving efficiency, safety & data optimisation"
Eztek L m ted - B ackburn ndustr a Estate – Aberdeen Un ted K ngdom AB21 0RX
Te +44 (0)1224 791977 Fax +44 (0)1224 791399 Ema *sales@eztek co uk* Web *www eztek co uk*
Registered n Scot and Nr 146531 reg strat on address Newhouse, Tyrebagger, C nterty, K ne ar, Aberdeen, AB21 0TT

- Zone ATEX comp ant Harsh Env ronment Computer
- 7" H gh Br ghtness TFT P65 D splay
- Computer and data acqu s t on e ectron cs a enc osed w th d sp ay
- USB ports for standard PC connect on & memory st ck
- 2 Ana ogue 4-20mA Channe nputs
- Ga van ca y so ated safety barr er (no S ground requ red)
- H gh accuracy and reso ut on
- Rea T me Record ng software
- Bu t n L th um Batter es for remote operat on
- Safe Area Battery Charger un t
- 0 to +50 degC operat on temperature range
- S mp e operat on

Logger Hardware

The system cons sts of an ndustr a spec f cat on computer comb ned w th data acqu s t on e ectron cs and th um batter es wh ch are housed n a sea ed P65 d ecast enc osure Th s harsh env ronment computer benef ts from a 'state of the art' h gh br ghtness 7" LED d splay prov d ng a screen reso ut on of 800 x 480 The screen prov des a c ear rea t me d sp ay of measur ng transducers n d g ta format and xy graph

S x momentary push button sw tches be ow the screen a ow for s mp e software setup adjustments; e sca e adjustment & graph scro ng

An add t ona sw tch togg es the power of the un t ON & OFF and can tr gger a power save mode An ntegrated LED f ashes when n power save mode to nd cate the un t s ogg ng data

The power save mode automat ca y sw tches the d sp ay back ght off after 5 m nutes Th s s necessary to ach eve ong test resu ts from the m ted battery power The user can press the ON/OFF sw tch to br ng the d sp ay back on

Connectors are ocated a ong the top s de of the enc osure These are for attach ng the sensors, battery charger, memory st ck and desktop/ aptop connect on

On comp et on of record ng data the un t can be connected to a standard desktop or aptop v a a USB ead for up oad ng and down oad ng of data Data can be opened d rect y from Exce to generate graph curves A ternat ve y data can be arch ved onto a USB memory st ck

The USB ports and battery charger are on y su tab e for safe area use

"Improving efficiency, safety & data optimisation"
Eztek L m ted - B ackburn ndustr a Estate Aberdeen Un ted K ngdom AB21 0RX
Te +44 (0)1224 791977 Fax +44 (0)1224 791399 Ema *sales@eztek co uk* Web *www eztek co uk*
Registered n Scot and Nr 146531 reg strat on address Newhouse, Tyrebagger, C nterty, K ne ar, Aberdeen, AB21 0TT

Software

A bas c software package s nsta ed on the ogger Th s software vers on runs on a W ndows CE p atform

Ca brated transducer measurements are d sp ayed as rea t me d g ta va ues Sensors can be recorded and curves d sp ayed on a xy rea t me graph

The scro ng graph v ew a ows the user to v ew over a t me per od def ned w th n the setup

Push button sw tches a ow the user to adjust measurement sca es on the graph They a so a ow the user to scro back and forth thru recorded graph pages

The recorded data s saved under a f ename that comb nes the test start date and t me

Data s extracted onto a memory st ck w th n a safe area on y

Both battery power and memory used nd cators are d sp ayed as percentages

Full software version on standard PC

Attach ng the harsh env ronment computer v a the USB connector to a standard desktop/ aptop PC w a ow for up oad of data and setup of ogger ca brat on, t me and date

W th the up oaded data the user can p ayback recorded tests and add the fo ow ng test data; Techn c an, Company Locat on, We No , Assemb y No , Job No & Ser a No

A data s then d sp ayed w th n the report and pr nted f requ red

An opt on a ows for a recorded test data to be compressed onto a s ng e graph Th s d sp ays the comp ete durat on of the test from beg nn ng to end

Both software packages feature an auto sca e funct on

Hardware Specification

Display

S ze	7" LED TFT
Screen Reso ut on	800 x 480
Br ghtness	280 cd/m2
V ew ng Ang e	60°
Back ght type	LED

Computer Hardware

CPU	520 MHz
RAM	64 Mb
SDCARD	2 Gb
Ports	1 x USB Dev ce
	1 x USB Host

Operating System

W ndows CE 5 0

Data Acquisition Electronic Interface

nput Channe s	4 x 4 20mA
Samp e rate	4 KHz

Enclosure

Type	D ecast
Sea Rat ng	P 65
Operat ng Temperature	0 to 50 °C

Additiona Notes

Battery Duration:	*60hrs continuous usage from fully charged*
Charging Duration:	*3hrs from flat*
Battery Charger:	*100 to 250 VAC (50 or 60 Hz)*

Safe area operation only