Introduction to Pigging & a Case Study on Pigging of an Onshore Crude Oil Trunkline

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Abstract: **- While buildup in a pipeline can cause transmittal slows or even plugging of the pipeline, cracks or flaws in the line can be disastrous. A form of flow assurance for oil and gas pipelines and flowlines, pipeline pigging ensures the line is running smoothly.**

In the context of pipelines pigging refers to: The practice of using devices known as "pigs" to perform various maintenance operations on a pipeline. This is done without stopping the flow of the product in the pipeline.

Pigs are introduced into the line via a pig trap, which includes a launcher and receiver. Without interrupting flow, the pig is then forced through it by product flow, or it can be towed by another device or cable. Usually cylindrical or spherical, pigs sweep the line by scraping the sides of the pipeline and pushing debris ahead. As the travel along the pipeline, there are a number functions the pig can perform, from clearing the line to inspecting the interior.

The current paper focuses on understanding the theoretical & practical aspects of crude oil trunkline pigging. An OLGA model is used to predict the Wax deposition Mass, Peak thickness, Average Pig Velocity & Pig travel time. This model is based on actual pipeline condition, fluid parameter and previous pigging data. Actual results from Supervisory control And Data Acquisition (SCADA) and real time monitoring were found in agreement with the OLGA model. The OLGA model predicted nearly 110 kg of dissolved wax and in actual nearly 40 kg of wax was obtained after pigging the trunkline. The model also accurately calculated the pig velocity considering the backpressure & completed the run in nearly 42.5 hours. This shows that the model which we have developed is competent enough to predict the tunkline behaviour, with fine tuning and history matching more accurate results are possible in near future.

Keywords:- **Pig, pigging model, OLGA & SCADA**

I. INTRODUCTION

Pipelines represent a considerable investment on behalf of the operators and can often prove strategic to countries and governments. They are generally accepted as being the most efficient method of transporting fluids across distances. In order to protect these valuable investments, maintenance must be done and pigging is one such maintenance tool.

During the 1940s, pipelines in the United States were mainly pigged to remove paraffin to increase efficiency in crude oil pipelines in order to maximize flow conditions for the war effort. The pigging equipment utilized at that time was limited to a few applications while being very crude in nature. In today's world, pipelines are pigged for a variety of reasons and the pigging equipment used is designed by engineers to perform particular functions.[2]

Pigging is a widely utilized process which is the act of propelling a properly sized spherical or cylindrical device through the interior of a pipeline by manipulating the pressure & flow of the existing media, or by artificially introduced media or by mechanically pulling the device through the pipeline for the specific purpose of cleaning, inspecting or distributing inhibitor throughout the pipeline.

A pig is a device inserted into a pipeline which travels freely through it, driven by the product flow to do a specific task within the pipeline. These tasks fall into a number of different areas:

- Utility pigs which perform a function such as cleaning, separating products in-line or dewatering the line.
- Inline inspection pigs which are used to provide information on the condition of the pipeline and the extent and location of any problem (such as corrosion for example).
- Special duty pigs such as plugs for isolating pipelines.[9]

One theory is that two pipeliners were standing next to a line when a pig went past. As the pig travelled down the line pushing out debris, one of them made the comment that it sounded like a pig squealing. The pig in question consisted of leather sheets stacked together on a steel body. Without doubting the authenticity of the story, it does indicate that these tools have been around for some time. Another theory is that PIG stands for Pipeline Intervention Gadget.[13]

The first pigging operation took place around the year of 1870, a few years after Colonel Drake discovered oil in Titusville, Pennsylvania. Before pipelines were used for transporting it, the oil was trucked to the refinery by horse-drawn tank wagons. This proved to be very difficult during winter months because of heavy snows and frozen wagon tracks, and in wet weather when wagons would sink in the mud. To improve upon this method of transportation, a pipeline was constructed, the material of which is not recorded, but each length of pipe was almost certainly joined by the bell-and-spigot method that we see today in plastic pipe. After transporting crude oil for a year or two through this pipeline, the flows began to decrease, and the pumping pressure increased, indicating that there were deposits building up on the inside walls of the pipe. Many things were tried to remove the paraffin deposits, but nothing worked effectively for any period of time. Eventually the idea of pumping something through the pipeline was considered. It has been suggested that a bundle of rags tied in a ball was used, and with positive results. Later, bundles of leather were used in place of the rags. Leather will swell when wet, so it created a tight seal going through the pipeline.[3]

During the construction of the line, pigs can be used to remove debris that accumulates. Testing the pipeline involves hydro-testing and pigs are used to fill the line with water and subsequently to dewater the line after the successful test. During operation, pigs can be used to remove liquid hold-up in the line, clean wax off the pipe wall or apply corrosion inhibitors for example. They can work in conjunction with chemicals to clean pipeline from various build-ups. Inspection pigs are used to assess the remaining wall thickness and extent of corrosion in the line, thus providing timely information for the operator regarding the safety and operability of the line. Pigs (or more specifically) plugs can be used to isolate the pipeline during a repair.[19]

There are different types of pigs available in the market. Choosing the correct pig is an involved process but if performed in a methodical way, the right choice can be made. It is important to set the objective and define the task that the pig has to perform. This may be removal of a hard scale in an 8” line for a cleaning pig or the location of corrosion pits in a 24” sour gas line for an inspection pig for example. Operating conditions can sometimes dictate the type of pig that must be considered. For example, an ultrasonic pig requires a liquid couplant around the pig and this may be difficult to achieve in a gas pipeline.

For economic reasons, a number of dual diameter pipelines have been designed and built in recent years. An existing riser or J-tube at a platform may require that there is a difference between the pipeline and the riser diameters. Tying a line into an existing pipeline may result in a change in diameter from one to the next. Dual and Multi-diameter pigs have had to be designed and tested to allow such systems to be pigged.[11,13,23]

These include pre-commissioning pigs for dewatering the lines; operational pigs to allow liquid hold-up to be removed from gas lines and inspection pigs to provide information on the line. Typical examples of dual diameter lines include a 10” x 8” line, a 20” x 16” and a multi-diameter line 11” x 12” x 14”. The biggest line is the Åsgard gas export line, which is 28” x 42” in the Norwegian sector of the North Sea. This can be both pigged and inspected.

Pigging frequency depends largely on the contents of the pipeline. Some sales gas pipelines for example are normally never pigged. This is since there is little by way of liquid to remove or debris / corrosion products in the line. On the other hand, production oil lines can suffer from wax deposition, which must be managed in order to allow production to continue.

It is difficult to give general guidance on this, as the pigging frequency must be set for each specific pipeline. The general understanding is that a pig is a valuable flow assurance tool and a decision can be reached with the operator on the frequency of pigging based on the flow assurance analysis of the line and in conjunction with the pigging specialists. Likewise, inspection intervals should be based on discussions between integrity management and the pig vendors.[1]

II. REASONS FOR PIPELINE PIGGING [15, 21]

Although each pipeline has its own set of characteristics which affect how and why pigging is used, there are basically three reasons to pig a pipeline:

- To batch or separate dissimilar products;
- For displacement purposes;
- For internal inspection.

The pigs which are used to accomplish these tasks can be divided into three categories:

- Utility Pigs, which are used to perform functions such as cleaning, separating, or dewatering.
- In Line Inspection Tools, which provide information on the condition of the line, as well as the extent and location of any problems.
- Gel Pigs, which are used in conjunction with conventional pigs to optimize pipeline dewatering, cleaning, and drying tasks.

The type of pig to be used and its optimum configuration for a particular task in a particular pipeline should be determined based upon several criteria, which include:

III. CRITERIA FOR PIG SELECTION [20,24]

- The purpose
  - Type, location, and volume of the substance to be removed or displaced in conventional pigging applications,
  - Type of information to be gathered from an intelligent pig run,
  - Objectives and goals for the pig run.
- The line contents
  - The contents of the line while pigging,
  - Available vs. required driving pressure,

- Velocity of the pig.
- Characteristics of the pipeline
  - The minimum and maximum internal line sizes,
  - Maximum distance pig must travel,
  - Minimum bend radius, and bend angles,
  - Additional features such as valve types, branch connections, and the elevation profile.

IV. HOW PIGS WORK [6, 14, 18, 22]

Pigs are designed so that sealing elements provide a positive interference with the pipewall. Once inserted into a line, pigs are driven through the line by applying pressure in the direction of required movement. A pressure differential is created across the pig, resulting in movement in the direction of the pressure drop. In operational lines, this pressure is applied by the line product, whereas, in un-commissioned lines, the propelling medium can be chosen to suit the task being carried out, e.g. water for flooding or dry air or nitrogen gas for dewatering. Note: Sufficient flow is also required to ensure pig movement at a suitable velocity. Once the force behind the pig becomes greater than the opposing frictional force, the pig will move in the direction of the applied force (pressure). The pressure at which the pig begins to move is known as the "break-out" or "stiction" pressure. This tends to be greater than the pressure required to maintain movement and is characterised by a pressure rise followed by a pressure drop to a plateau for the pig launching operation. Depending on the design of the sealing element, pigs can either be run in a single direction, or run backwards or forwards through a line. Pigs that can only be run in one direction are known as unidirectional pigs, and have polyurethane sealing elements of the cone or cup design. These types of pigs are generally used in established lines known to be piggable. Sealing elements in the bidirectional pigs are flat, providing an identical seal in either direction, and therefore, giving more adaptability in previously unpigged lines. Additional sealing elements can be added to pigs, leading to better sealing properties along with a higher pressure differential required to drive the pig. Support for the pig to ensure it remains central in the line can be provided by either support discs, or, for large diameter pigs, centralising wheels. Pigs come in various varieties, the most common being mandrel, single bolt, solid cast, foam, articulated, and spheres.

V. PIGGING FUNCTIONS [10,12,16]

Fluid Separation Pigs form a solid barrier between dissimilar fluids, e.g. liquid and gas. As such, pigs can be utilised in a train to "batch" chemicals or other fluids to perform a function. A good example of this would be the following pig train. The first two slugs of fresh water provide desalination for a line previously flooded with seawater, while the glycol slugs aid in dehydration and hydrate inhibition upon the introduction of product. The whole train is driven by nitrogen gas.

Displacement: As there is a solid interface formed between the pipe wall and the pig sealing element, any fluid in the line (liquid or gas) is displaced from the line as in the pig train above. Inevitably there is some bypass due to surface roughness, weld penetration, and seal bypass.
Cleaning: Like the process for displacement, the positive interface between the pig and the pipe wall imparts a cleaning action on the pipewall. This can be further enhanced by the addition of brushes, scrapers, or even more aggressive tools to the pig. For lines where ferrous debris is expected, magnets attached to the pigs can add a pick-up action for removal of magnetic debris. The turbulence within the fluid flow will hold any small, solid debris in suspension, effectively sweeping it out of the line. The use of bypass ports through the pig can aid this sweeping effect. Waxes and sludges tend to adhere to the pig brushes and scrapers and are generally "ploughed" through the line.

Gauging: In order to identify any major restriction in flow area through a line a simple metal plate is attached to the pig to provide an internal line gauge. Generally sized to 95% of the pipeline internal diameter (95% nominal or 95% minimum, dependant on specification being used), the gauge plate tends to be made of a soft metal such as aluminium and is chamfered on the leading edge. It is common to "petal" the gauge plate with short, radial cuts to minimise the risk of the pig becoming stuck. These radial cuts through the gauge plate allow the plate to bend more easily if an obstruction is encountered.

VI. TYPES OF PIGS [5,8]

Batching Pig: Also known as a swabbing pig, the batching pig is designed to act as a simple barrier between dissimilar fluids or to provide a sweep of a line.

Gauging Pig: The inclusion of a simple gauge plate, made of a soft metal (generally aluminium), on batching pigs provides the function of confirming the integrity of the flow area of the pipe. Any major intrusions into the line will cause damage to the gauge plate, highlighting there is a problem, though not highlighting where.

Cleaning Pig: Pigs can be configured with various tools to aid cleaning. Circular brushes, spring-mounted brushes, scrapers, or plough blades for waxes and sludges, or more aggressive tools such as carbide "pins" for removal of scales.

Magnetic Pig: Inclusion of powerful rare earth magnets on the circumference of the pig mandrel allows the pig not only to lift ferrous debris from the line, but can also provide the secondary function of activating pig signallers. Foam pigs also allow the addition of gauge plates, brushes, abrasives etc., although these are either fitted into the pig using bolts, or by direct casting into the polyurethane coating.

Intelligent Pigs: Research and development into inline inspection tools began in the late 1960's. Advances in technology have lead to pigs that can carry out complex tasks and data logging as they traverse the line. Mapping, geometry measurement, crack detection, measurement of metal loss, and many other tasks can be carried out. Intelligent pigging is now an industry within an industry. Gel Pigs: For certain tasks and in certain conditions, a viable alternative to running mechanical pigs is the use of gel pigs. Rather than use a solid barrier between fluids, a gelled substance can perform the same task. Various mediums can be gelled, including water (fresh and salt), glycol, methanol, solvents, diesel, and crude. The gels can be designed specifically to a required viscosity or cast as solid with chemical components designed to break down the gel after a given time or when a set temperature or pH has been reached. Gels have their limitations and are not generally suitable for long runs, in dry pipelines, or where the propelling medium is gas because they tend to suffer from "gas cutting" or excess bypass.

VII. HISTORY OF INTELLIGENT PIGGING [4,7]

The original concept of using a pig to inspect a pipeline came from Shell Research in 1963. Shell patented the idea of an eddy current inspection tool. Tuboscope bought the patent and changed the design to an MFL (magnetic flux leakage) system based on their existing drill pipe inspection techniques. Out of this research the first MFL tool was created-it was called the 90° Tool. In 1964 started commercial operation it used a 6 coil sensor and inspected bottom ¼ of the pipeline & then used a 7 channel tape recorder which did not have a measuring wheel.

Timeline History of Intelligent Pigging[7]

- 1964: First commercial MFL pig (Tuboscope)
- 1966: Firstfull-circumference MFL pig (Tuboscope)
- 1971: Other vendors introduce low-resolution MFL pigs
- 1978: First high-resolution MFL pig (British Gas)
- 1986-1996: Other vendors introduce high-resolution MFL pigs
- 1986: First ultrasonic pig for corrosion in liquid lines
- 1992: Prototype ultrasonic crack-detection pig (PII)
- 1993-present: Continuing improvements in PII wheeled ultrasonic pig
- 1997: Pipetronix ultrasonic angle-beam crack detection pig
- 1997: First reduced-port pigs
- 1997-present: Development of inspection capability for mechanical damage
- 1998-present: First circumferential (transverse field) MFL pigs

Some new, “smart” pigs have GPS capabilities that can assist in mapping a pipeline. This helps maintenance crews save time and money by pin-pointing exactly where is a pipeline is run, instead of having to excavate a large area to reach a specific location in the line.

Intelligent PIG performs following actions:

- Measures and records information used to assess pipeline
- Performs nondestructive assessment of pipeline defects
- Performs an internal assessment of the pipe bore diameter

VIII. REASONS FOR PIGGING [17]

Precommissioning: When new pipelines are built, they generally need to be cleaned of construction debris and prepared for hydrostatic testing. This is generally done by utilising a pig train consisting of cleaning, gauging, and batching pigs to flood the line. Depending on the medium to be transported in the line, further pigging may be required for dewatering and drying operations.

Commissioning: As the product is introduced into the line, a batching pig or pigs can be used to separate the product from the medium currently in the line.

Operational Pigging: During the life of a line, operational pigging is a cheap effective way of maintaining flow and minimising back pressure. Pigs can be used to mechanically clean waxes and other hydrocarbon build-ups, or chemicals can be batched between pigs to provide chemically enhanced cleaning. Inline inspection is generally carried out as part of a routine maintenance plan.

Decommissioning: Whether pipelines reach the end of their useful life, or have their use changed (e.g. changing a production line to a produced water disposal line), they generally require some form of cleaning. Again, mechanical and chemical means can be used to allow subsea disconnection/reconnection, and in some cases pipelines can be dewatered for recovery and reuse.

IX. CASE STUDY

The present case study uses OLGA to simulate the pigging operations & PVTsim at its backend. Continuous monitoring of pressure & temperature was done through SCADA system.

Brief about OLGA: The OLGA dynamic multiphase flow simulator models time-dependent behaviors, or transient flow, to maximize production potential. Transient modeling is an essential component for feasibility studies and field development design. Dynamic simulation is essential in deepwater and is used extensively in both offshore and onshore developments to investigate transient behaviour in pipelines and wellbores.

The OLGA Wax module calculates the deposition and transport of wax components along the pipeline. It models the effects of increases in pipeline roughness, decreases in pipeline diameter, and the increased apparent viscosity of the oil phase with precipitated solid wax particles.

Wax deposition occurs on the inside surface of a flow line due to molecular diffusion when the pipe wall temperature falls below the wax appearance temperature (WAT). Wax precipitation occurs in the oil bulk flow when the bulk temperature is below WAT.

The Wax module supports tuning fluid properties related to molecular diffusion, dissolution, shear related wax transport, and effective viscosity of an oil/wax mixture to dynamically model wax deposition, dissolution, and transport effects. The OLGA simulator also simulates pigging operations for wax layer removal and transport.

Brief about PVTsim: PVTsim is a versatile equation of state (EOS) modeling software that allows the user to simulate fluid properties and experimental PVT data. The wax module evaluates wax formation conditions from an ordinary compositional analysis, quantify the amount of wax precipitate, run flash calculations, and plot wax formation conditions through PT curves. If data is available, it is also possible to tune the wax model to an experimental cloud point or to experimental wax content in the stock tank oil. The amount of wax precipitate may be calculated as a function of P for constant T or as a function of T for constant P and quantitative flash calculations will consider gas, oil and wax. Additionally, there is an option to account for the influence of wax inhibitors.

The trunk line between GGS1 & GGS2 is being pigged for scrapping of wax once in 30 days irrespective of weather. Simulation has been carried out in OLGA 7.2 to predict the wax deposition propensity. The fluid modeling has been carried in PVTSim18 to capture the fluid parameters.

Trunk line details

No.	Particulars	Unit	Value
1.	Line size	inches	8
2.	OD	inches	8.625
3.	Grade		API X-46
4.	Wall Thickness	Inches	0.277
5.	ID	inches	8.071
6.	Length	km	40
7.	Burial depth	m	1.2
8.	Coating Coal tar enamel	mm	4
9.	Pumping rate	M3/hr	12-28
10.	Dispatch temperature	Deg C	55
11.	Dispatch viscosity	cP	20
12.	Pressure at end (TPL / Tank)	Bar	18 / 1
13.	Fluid Temperature at Ramol end	Deg C	27
14.	Fluid viscosity at end	cP	~ 800 cP
15.	Ambient temp (Max/Min)	Deg C	38 / 10
16.	Crude dispatch pumps	Rated Pressure	60 kg/cm2
		Rated flow	2 x 12 m3 hr, 1x 16 m3/hr

Source: ONGC Labs

Physical Characteristics of crude oil

No.	Properties	Value
1.	Sp. Gravity 60/60°F	0.864-0.868
2.	API Gravity 60°F	32
3.	Pour Point (°C)	36-42
4.	Viscosity Dry crude cP	363 @45 °C, 40300@25°C
5.	Viscosity emulsion (50% w/c) cP	233 @45 °C, 22500@25°C
6.	Viscosity emulsion (90% w/c) cP	233 @45 °C, 4373@25°C
7.	STO(Wax) WT %	22-26

Source: ONGC Labs

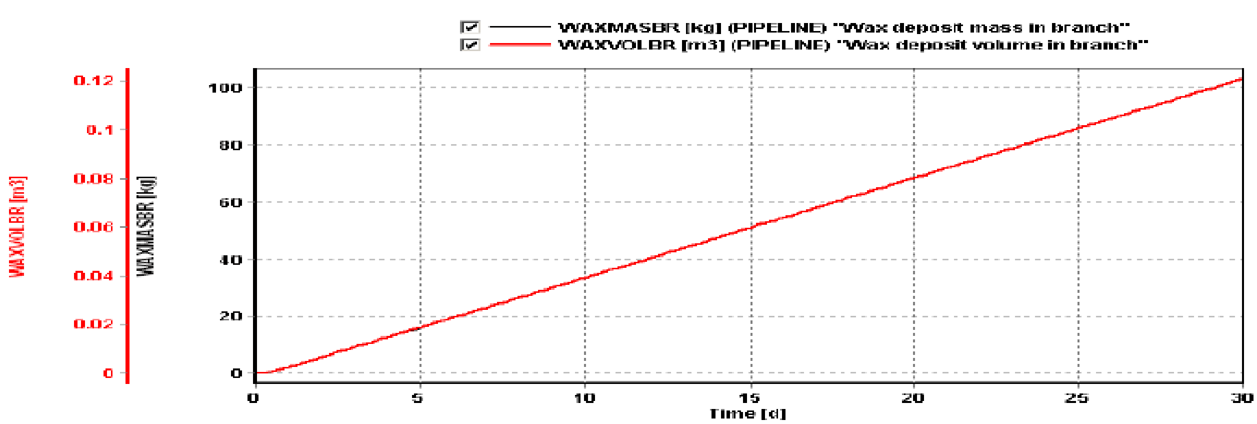

Fig 1: Wax Mass vs Days

Form the above graph it can be seen nearly 110 kg of wax mass has been predicted. At the pig receiving station nearly 40 kg of un-dissolved wax is observed. So it is very rightly & modest prediction that 70 kg of wax will be in semi dissolved state.

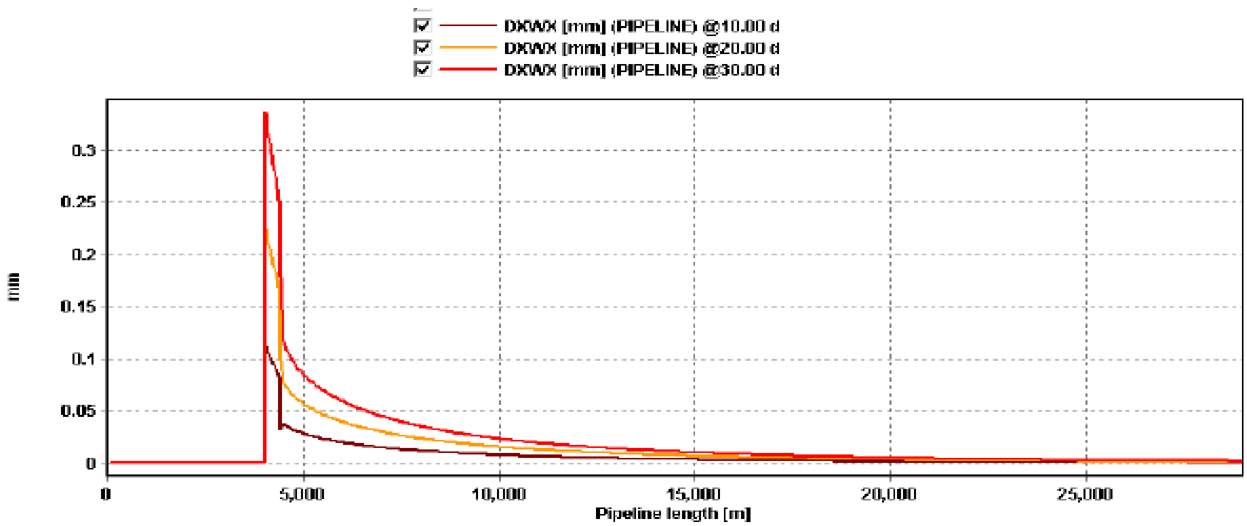

Fig 2: Wax thickness along the trunkline

It can be seen that a maximum wax thickness predicted is 0.32mm at nearly 4.5 kms from the pig launching station i.e GGS1. The reasons for this are change in trunkline orientation & temperature gradient. These factors greatly influence the wax deposition. It can be seen that later wax deposition is constant as equilibrium is achieved & irrespective of 10, 20 or 30 days its remains nearly the same.

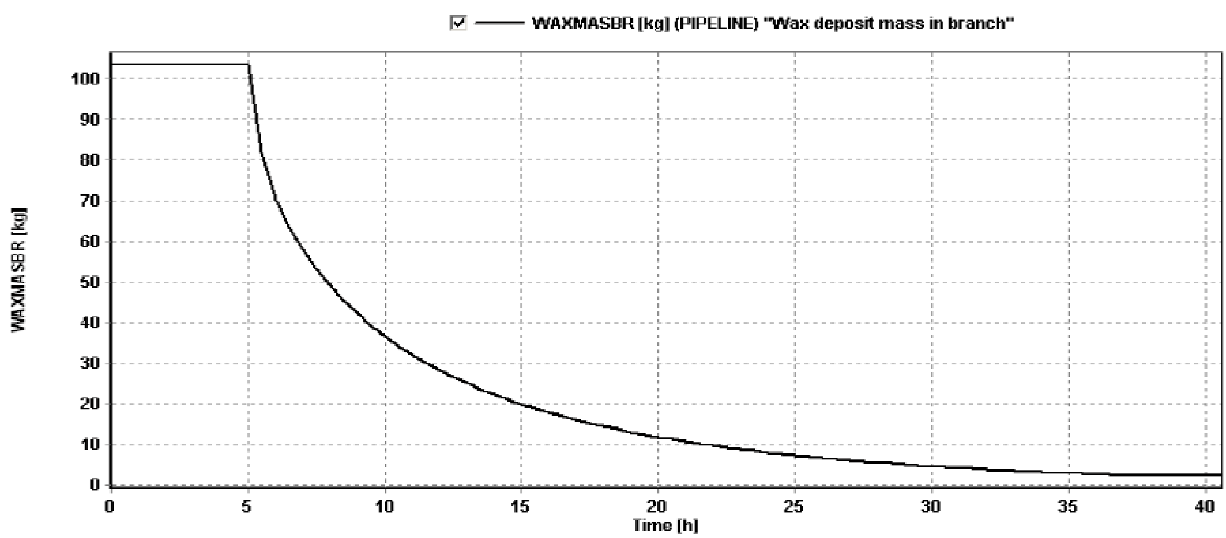

Fig 3: Wax removal by pigging after 30 days deposition

From the prediction it can be seen that distance propensity of wax deposition is nearly 4.8 kms from GGS1. An anti exponential nature is predicted further due to equilibrium. A near correct estimate of nearly 41.5 hours has been predicted whereas 42.5 hours had been taken for the pig to travel across the trunkline.

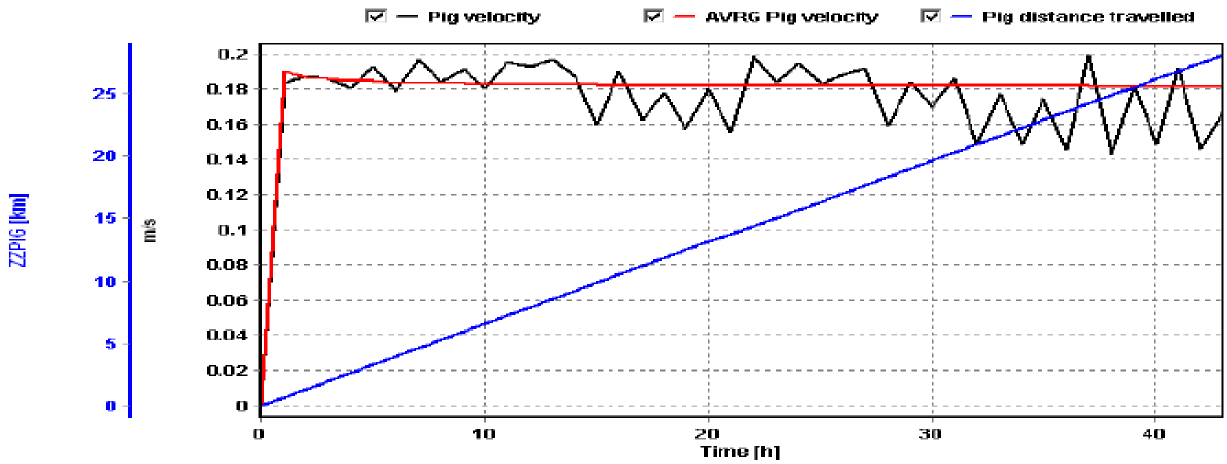

Fig 4: Pig velocity and travel time

The figure shows pig velocity, average pig velocity & the pig distance travelled. The average pig velocity is 0.182m/s.

X. PRESSURE-TEMPERATURE VARIATION IN GGS1-GGS2 TRUNK LINE FROM SCADA

Temperature and pressure profile for 6 months from November to April.

O Temperature X Pressure

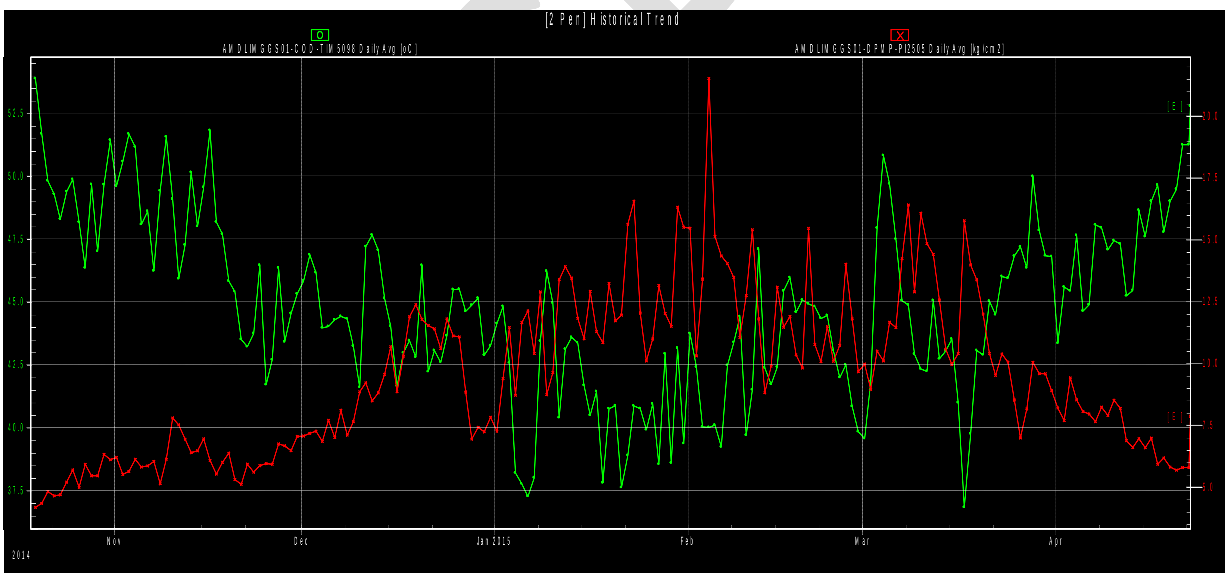

Fig 5: Temperature and pressure profile for 6 months

The above Figures are the flow rate-pressure and pressure–temperature variation in GGS1-GGS2 trunk line. During winters November to February, the drop in temperature leads to increased wax deposition in the pipeline. This results in high pressure inside the pipeline. While in April due to increase in temperature, wax deposition decreases so pressure also decreases. Figure also shows increase in backpressure (February 4 pig launched) due to wax deposition & it is further increased due to launching of pig. After the pig is received at GGS2 receiving station, immediate pressure drop is observed. A gradual increase in trunk line temperature can also be seen with decrease in pressure. One important parameter which plays a deciding factor in wax deposition in trunk line is the Stock Tank Oil's water cut. Higher water cut makes wax inter molecular wax bonding stronger which further increases pressure. An increase in water cut can also cause to trunk line to corrode thereby providing active sites for nucleations for paraffin's. The current simulation gives good results in a 30 day pigging cycle, but as the quantity of liquid to be transported via trunk line will increase this pigging frequency needs to be accordingly modified.

XI. RESULTS

The pigging case simulation results for winter conditions i.e ambient 11 ^{O}C reveal the following:-

No.	Particulars	Results
1	Wax deposition Mass in 30 days	~110 kg
2	Distance propensity from GGS-I	~ 4.8 kms
3	Peak thickness	0.32 mm
4	Average Pig Velocity	0.182 m/s
5	Pig travel time (GGS 1-GGS 2)	~41.5 hrs

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REFERENCES

[1]. Abdumula, M. Farag (2004). "Crude Oil Pipelines Inspection" Technology of Oil and Gas Forum and Exhibition.
[2]. Abdumula, M. Farag (2004). "Heavy Hydrocarbon Testing Methodology" The Micro CAD International Scientific Conference Hungary – Miskolc.
[3]. Abdumula, M. Farag (2003). "Influence of Paraffin Flocculation in Crude Oil Tran sported Pipelines with Economic View of Pigging Process"1st International Conference and Exhibition in Oil Field Chemicals. Libya -Tripoli.
[4]. Abdumula, M. Farag (2004). "Wax Precipitation in Crude Oil Tran sporting Pipelines". The Micro CAD International Scientific Conference Hungary–Miskolc.
[5]. Alyaari, M., (2011) "Paraffin wax deposition: Mitigation and removal techniques." SPE155412 pp: 1-10.
[6]. Barnea, D., Brauner, N. 1985. Hold-up of the liquid slug in two phase intermittent flow. Int. J. Multiphase Flow 11, pp. 43-49.
[7]. Barnea, D., Taitel, Y. (1986). Flow pattern transition in two-phase gas-liquid flows. Encyclopedia of Fluid Mechanics, Vol. 3, Gas Liquid Flows. Gulf Publishing, Houston.
[8]. Beggs, H. D., Brill, I P., (1973) A study of a two-phase flow in inclined pipes. I Pet. Technology, pp. 607-617.
[9]. Edwards, Lyndon and Endean, Mark, (1990) Manufacturing with Materials, Butterworth Scientific Ltd, ISBN 0408 027770 3.
[10]. Ernst, H and Merchant, M E. (1941) Chip formation, friction and high quality machined surfaces, Surface Treatment of Metals (American Society of Metals).
[11]. Fang, N. (1997) An auxiliary approach to the experimental study on chip control: A kinematically simulated test, Proceedings ofthe Institute ofMechanical Engineers, Vol.212, Part B.
[12]. Garcia, Maria del Carmen; Carbognani, Lante; Urbina, Argelia; Orea, Miguel. (1998). Paraffm deposition in oil production. Oil composition and paraffin inhibitors activity, Journal of Petroleum Science and Technology, Vol. 16, Issue 9-10, Oct/Nov, 1001-1021.
[13]. Garcia, Maria del Carmen; Carbognani, Lante; Urbina, Argelia; Orea, Miguel. (2000) The influence of alkane class-types on crude oil wax crystallization and inhibitors efficiency, Journal of Petroleum Science and Technology, Vol. 25.
[14]. Glauert, M B. (1956) The wall jet, Journal of Fluid Mechanics, 1, Part 5, 625-643.
[15]. Gupta, A., and Sircar, A., (2015) Need of Flow Assurance for Crude Oil Pipelines: A Review. International Journal of Multidisciplinary Sciences and Engineering, Vol. 6, No. 2 pp: 1-7.
[16]. Lee, E Hand Shaffer, B W. (1951) The theory of plasticity applied to a problem of machining, Journal of Applied Mechanics, Trans. A.S.ME., 73, 405.
[17]. Loewen, E. G., Shaw, M. C., (1954) Trans. Am. Soc. mech. Engrs. 76, 217.
[18]. Mendes; Braga; Azevedo; (1998) Correa. Resistive Force of Wax Deposits During Pigging Operations, Journal of Energy Resources Technology, ETCE99-6671.
[19]. Merchant, ME and Zlatin, (1945) N. Mechanical Engineering 67, p737.
[20]. Michelbach, S. Origin, (1995) Re-suspension and settling characteristics of solids transported in combined sewage, Water Science Technology, Vol. 31, No.7, 69-76.
[21]. Mozes, G Y; Freund, M; Csikos, R; Keszthelyi, S. (1982) Paraffin Products- Properties Technologies Applications, Elsevier Scientific Publishing Company.
[22]. http://psa-online.com/frequently-asked-questions.php
[23]. https://en.wikipedia.org/wiki/Pigging
[24]. http://www.rigzone.com/training/insight.asp?c_id=19&insight_id=31