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Laboratory Deposition Apparatus to Study the Effects of Wax Deposition on Pipe Magnetic Field Leakage Signals

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Abstract. Accurate technique for wax deposition detection and severity measurement on cold pipe wall is important for pipeline cleaning program. Usually these techniques are validated by conventional techniques on laboratory scale wax deposition flow loop. However conventional techniques inherent limitations and it is difficult to reproduce a predetermine wax deposit profile and hardness at designated location in flow loop. An alternative wax deposition system which integrates modified pour casting method and cold finger method is presented. This system is suitable to reproduce high volume of medium hard wax deposit in pipe with better control of wax deposit profile and hardness.

1 Introduction

An extensive search for accurate and practical online measurement technique to detect wax deposition location and estimate its severity in subsea pipeline is ongoing due to insufficiency of conventional techniques. Various techniques are being developed and put on testing such as acoustic reflectometry, heat transfer, heat pulse, ultrasonic, strain measurement and tracer [1-5]. Typically, these experiments are conducted using flow loop while the thickness of wax deposit are validated by conventional techniques i.e. pressure drop method and gravimetric method.

Despite the fact that these conventional techniques to determine wax deposition thickness themselves are inaccurate, the kinetics and mechanism of wax deposition in flow loop are also still not fully understood. These inherent complications in reproducing wax deposit with similar specifications. Overall, these issues would depress the reference accuracy for the measurement techniques in testing. It is also noted that less attention was given by previous researchers on the deposit hardness evaluation which is known essential in designing a pig and cleaning program. Hence, we believe if the deposition process can be conducted with less influencing parameters, while the profile and hardness can easily be controlled prior to measurement, the objective of validating the new technique can appropriately be achieved.

At present, an attempt to validate a new magnetic technique which utilizing magnetomechanical effect is underway. The test shall be conducted via hydrostatic test setup. Knowledge of the wax deposit profile and its behaviour is crucial for the success of this technique validation. Since this project initiation, an extensive search for wax deposition method in pipe has been ongoing. Three methods have been identified including flow loop, cold finger and pour casting [6-8]. Based on these methods, an alternative deposition method is developed specifically to suit the study. In this paper, the

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basic requirements for wax deposition characteristics to yield accurate and repeatable data are first established. Principle of deposition is elaborated. Subsequently, the design and operation of a deposition apparatus and characteristics of wax deposit are presented.

1.1 Requirements for wax deposition

Design employed modified pour casting and cold finger methods that provide control over the wax-oil composition, mould dimension and thermal condition. The variables that control deposition led to the following experimental apparatus specifications:

- The deposition method should deposit wax at designated location in a pipe with predetermine profile i.e. thickness, longitudinal and circumferential size with acceptable accuracy.
- The deposited wax hardness can be determined in advance, consistent and able to withstand the given internal hydrostatic pressure.
- The deposit wax should not easily displace during minor surge pressurization in the pipe.
- The deposit wax should remain solid state at room temperature and test pressure.
- The deposition method or removal should not allow the pipe to be heated to 60°C or higher as this would significantly alter the magnetic field distribution on the test pipe.
- Deposit samples should easily be removed as one piece for subsequent analysis.
- Since deposition time and temperature are crucial in this aging process, both parameters need to be well defined and controlled through the deposition process.
- The system need to be in laboratory scale. Due to large surface area for deposition, relatively high volume of wax is required, so that wax deposition would not significantly deplete in wax content at particular area which may produce a loose structure.

2 Constructions of deposition apparatus

2.1 Basic principle

The main mechanism that may control wax deposition in this method is molecular diffusion. Although gravity settling mechanism is not preferable, the occurrence cannot be ignored due to the deposition setup.

The standard assumption about the driving mechanism for wax deposition is that a temperature gradient from the bulk oil towards the pipe wall causes a concentration gradient of dissolved wax. This concentration gradient determines the diffusion of wax molecules leading to a change in wax deposition thickness over time. The wax diffusion process can be described by the following steps:

1. Gelation of waxy oil (formation of the incipient gel layer) on the cold surface
2. Diffusion of waxes (hydrocarbons with carbon number greater than critical carbon number (CCN)) towards the gel layer from the bulk.
3. Internal diffusion of these molecules through the trapped oil
4. Precipitation of these molecules in the deposit
5. Counterdiffusion of de-waxed oil (hydrocarbon with carbon number lower than the CCN) out of the gel layer

As the deposit thickness grows, the insulating effect increases and the driving force for further deposition significantly diminishes. Hence there is virtually no increase in the film thickness. However, there is still a thermal gradient across the deposit. This gradient may result in an internal mass flux, which in turn causes the wax content of the gel to continually increase. The increase in the wax content of the gel deposit with time from the last three steps above leads to hardening of the deposit which is aging. The wax content has a strong function of aging time and temperature difference across it. The wax content of the gel deposit increases with time until it reach plateau as observed by Singh [9]. It also should be noted that, CCN depends on the composition of the wax oil mixture and wall temperature. System with higher CCN results from aged deposit will have a higher melting point and higher mechanical strength [10]. This mechanism applies for both cold finger and flow loop but not obvious for pour casting method as the cooling time is rapid.

A new method is developed based on this concept. The basic setup of the mould and wax-oil pouring procedure is almost similar to the pour casting method by Wang [8] with minimal modification. However, wax aging is allowed to occur in the process. Basically in this method, the aging process and wax-oil composition are controlled in order to vary the wax deposit strength by region and sample. The temperature of wax-oil inside the mould is manipulated while the cold bath temperature outside the pipe is maintained at room temperature. The main reason of gradually reduced the wax-oil temperature in the mould, is to provide sufficient time for aging process. Wax deposition is only possible by dissolved wax molecule but not the precipitated wax crystal, so these heavier hydrocarbons are not available for wax deposition at lower temperatures. Hence, the deposit near the pipe wall shall have higher amount of solid wax in comparison to the inner layer. This will ease the internal mould release at the inner layer. On the other hand, the profile of wax is maintained while secure the breaking force of wax deposit at the pipe wall. As a result, the wax deposit will remain at the same position during the test. In addition, since it is close system, total amount of wax and oil in deposit will not change. Hence, the CCN and total wax characteristics can be vary by manipulating the wax-oil composition.

2.2 Operation of deposition apparatus

A schematic diagram of the wax deposition system in pipe is shown in Figure 1. The system consists of cold bath with water circulation to maintain the water temperature. Aluminium pipe acting as a mould is prepared according to the gap distance between the mould and pipe to create an annular space between them which is equivalent to deposit thickness. Retort stand and retort clamps are employed to align the mould in pipe. Rubber gaskets are placed at a required height to limit the longitudinal profile of the deposit wax. Heating rod and thermocouple which are connected to a temperature controller are placed inside the mould to continuously control the wax-oil temperature.

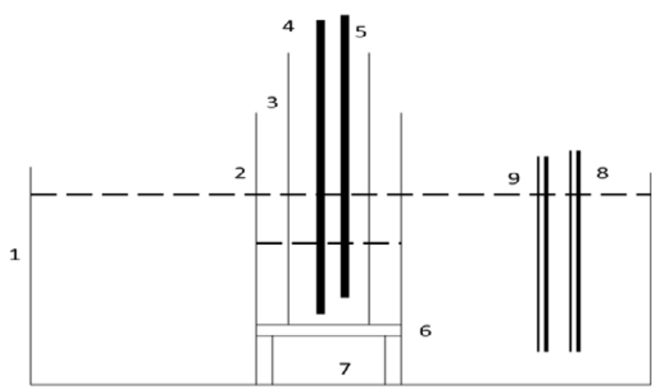

Figure 1. Wax deposition setup. (1) Cold bath, (2) pipe, (3) mould, (4) heating rod connected temperature controller, (5) thermocouple, (6) rubber gasket, (7) supporter, (8) cooling water inlet, (9) cooling water outlet.

This wax deposition setup is operated with the following procedure:

1. Wax is melted and mixed with oil at a desired percentage and kept at the temperature for 6 hours.
2. Properly locate and secure the gasket at the desired distance from the bottom of the pipe.
3. Place the pipe vertically inside the cold bath.
4. Fill the cold bath with water above of wax deposition designated level.
5. Heat the mould to the wax-oil melting temperature and accurately aligned the mould inside the pipe using the two retort clamps attached to a single retort stand.
6. Pour an accurate volume of melted wax slowly inside the mould according to the longitudinal length of wax needed to be deposited on the internal pipe wall

7. Elevate the mould a few millimetres off the based gasket for a while to allow the wax to completely fill the annulus gap between the mould and pipe from the bottom.
8. Place the heating rod and thermocouple inside the mould.
9. The wax oil temperature is maintained at 60°C for 24 hours. After that, the temperature is gradually reduced to room temperature with a few intervals with 1 hour stabilization period each.
10. Remove the mould with solid wax trap in the mould when there is no temperature difference between wax and water in cold bath.
11. The pipe with wax deposit is kept at constant temperature for 10 hours before test.

3 Results and discussions

A prototype of this system was built. The mixture of paraffin wax from Sigma Aldrich Company with a melting point of 53°C and kerosene (oil) was deposited inside the pipe with variations of oil contents i.e. 10%, 20% and 30% oil. Wax deposition based on the new system was conducted on an identical setup, pipe and mould consecutively. Gaskets were placed at 100mm from the bottom of 315mm vertical pipe. The mould outer diameter was 60mm and the pipe internal diameter was 112mm to produce annular gap of 26mm which was the thickness of the deposited wax. The volume of wax-oil mixture was 9680mm^3 for each test to produce 50mm length of wax deposition in the pipe. Same dimension of pour casting wax deposit sample was fabricated for comparison purpose.

3.1 Deposit profile

Figure 2 shows wax deposit samples from the new system and pour casting method. Clearly this new system was capable of giving good wax deposition profile i.e. longitudinal and circumferential as required. Deposition procedure and gasket connection were found to be important for the success of this wax deposition. Bottom of the wax deposit surface was flat, whereas the top part had a mark of depression approaching the centre. However, the mark was only started at a distance away from the pipe surface. Constant wax thicknesses at the pipe surface prior to a deep depression mark were most obvious for the least oil content samples. This may be due to the higher rate of molecular diffusion during the early stage of wax deposition which resulted from high concentration gradient between bulk fluid to the deposited gel and a sufficient aging process period. This also demonstrates that molecular diffusion dominates the early stage of deposition. In the latter stage, gravity settling and the volume shrinkage would occur which resulted in the depression mark observed. Conversely for pour casted samples, the mark started instantly and gradually across the inner radial diameter of wax from the pipe surface. This observation may be due to insufficient time available for aging process at the pipe wall.

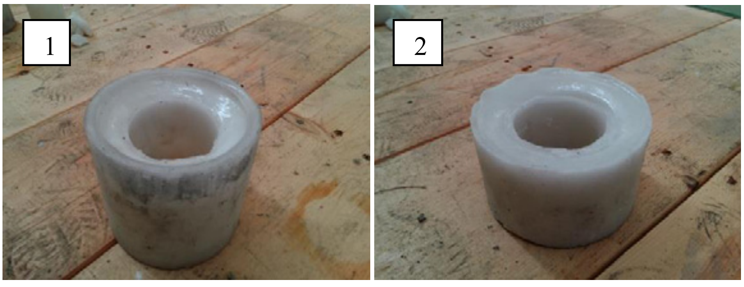

Figure 2. (1) Wax deposit using new system, (2) wax deposit using pour casting method.

It was also observed that thicknesses of deposited waxes were consistent with smooth surfaces at the inner wall in all new system samples. This indicates that the mould retrieval process is sufficient. The wax deposit structure was stable even after it was remove from the pipe and the dimension was maintained due to high hardness of each wax-oil mixture.

3.2 Deposit hardness

It was found that the hardness of wax deposits was reduced with the increment of oil content for all samples as tabulated in Table 1. The linear trend indicates that we can tailor the wax hardness by simply varying the oil content. However the hardness differences between inner and outer layer were most obvious for the new system samples in comparison to the pour casted samples. This reflects the effectiveness of the new system in enhancing the aging of wax deposit adjacent to the pipe wall.

Table 1. Average hardness of wax deposits.

Average shore hardness (Type D) from 5 measurements	10% oil content		20% oil content		30% oil content	
	New method	Pour casting	New method	Pour casting	New method	Pour casting
Inner layer	8.0	9.2	6.5	7.1	5.3	6.1
Outer layer	11.2	9.2	9.0	7.3	7.6	6.2

4 Conclusions

A small scale wax deposit setup has been constructed. The setup allows the wax deposit profile and hardness to be tailored according to test requirement. The temperature inside the mould and water bath are well defined and easily modelled. The reproducibility of the measurements has been demonstrated. The ability to conduct tests with high volume of wax makes it ideal for exploratory research programs in a larger scale.

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