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Review

Wax formation in oil pipelines: A critical review

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ABSTRACT

The gelling of waxy crudes and the deposition of wax on the inner walls of subsea crude oil pipelines present a costly problem in the production and transportation of oil. The timely removal of deposited wax is required to address the reduction in flow rate that it causes, as well as to avoid the eventual loss of a pipeline in the event that it becomes completely clogged. In order to understand this problem and address it, significant research has been done on the mechanisms governing wax deposition in pipelines in order to model the process. Furthermore, methods of inhibiting the formation of wax on pipeline walls and of removing accumulated wax have been studied to find the most efficient and cost-effective means of maintaining pipelines prone to wax deposition. This paper seeks to review the current state of research into these areas, highlighting what is so far understood about the mechanisms guiding this wax deposition, and how this knowledge can be applied to modelling and providing solutions to this problem.

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1. Introduction

Wax build-up is a complex and very costly problem for the petroleum industry, widely reported and studied by researchers in decades past (Reistle, 1928, 1932; Bilderback and McDougall, 1963; Haq, 1978). For subsea pipelines, in particular, it has become especially important to solve the issue of wax build-up, as large-scale oil production in colder regions will be faced with more severe wax precipitation (Smith and Ramsden, 1978; Asperger et al., 1981).

Wax precipitation within pipelines at and below the Cloud Point or Wax Appearance Temperature (WAT) can lead to gelling that inhibits flow by causing significant non-Newtonian behaviour and increasing effective viscosities as the temperature of a waxy crude oil approaches its Pour Point (Pedersen and Rønningsen, 2003). Alternatively, when just the pipeline wall is below the WAT, this promotes the deposition of a layer of paraffin molecules that can grow over time, constricting flow. This is especially problematic for pipelines in deep-sea environments, as, even in relatively warm climates, the water temperature will be on the order of 5 °C (Azevedo and Teixeira, 2003).

Some researchers, such as Carmen García et al. (2001) and Carmen García and Urbina (2003), have studied correlations between the properties of crude oils and their flowing properties, including the precipitation and deposition of wax during flow. Models have been developed to predict the onset of wax precipitation and the deposition of wax along pipeline walls. However, accurately modelling deposition in pipelines can be a complex and difficult undertaking, because, while precipitation is mainly a function of thermodynamic variables such as composition, pressure and temperature, deposition is also dependent on flow hydrodynamics, heat and mass transfer, and solid–solid and surface–solid interactions (Hammami et al., 2003). Only recently has a model been developed that incorporates correct analogies for heat and mass transfer.

This paper reviews cases where researchers have studied ways to model wax deposition and the aging of wax deposits in pipelines; methods of measuring wax build-up in pipelines; methods of inhibiting this deposition; wax removal methods; and restart procedures for pipelines gelled with waxy crude. In doing so, this paper, as one goal, seeks to show how our understanding of these mechanisms has developed, to highlight areas where further understanding of these mechanisms is still needed, and to show how well our current correlations can be applied to the accurate prediction of wax deposition. Furthermore, this paper seeks to highlight the progress that has been made in developing methods to mitigate and treat the formation of paraffin layers in pipelines.

2. Detection of deposited wax

2.1. Detecting blockages

In order to experimentally explore wax deposition in the field or to determine the locations of particularly large wax deposits or even complete plugs, methods are needed for detecting the extent of wax deposition at different points in a pipeline or of detecting the location of plugs. Pressure echo techniques can be used to find the location of a blockage by measuring the time for a pressure wave to be reflected back along the pipeline from the point of blockage (Chen et al., 2007). Alternatively, the pipeline could be pressurized and then a special tool with a calliper and video camera on a remotely-operated submersible could be used to measure the external diameter of the pipeline. Upstream of the blockage, but not downstream of it, an appreciable difference in the diameter can be detected when the pipeline is pressurized (Sarmento et al., 2004).

2.2. Detecting wax deposits

Traditional experimental methods for measuring the extent of wax deposits include direct methods such as pigging and the "take-out" method, in which a section of pipe is removed and the volume of wax inside measured. Additionally, pressure drop and heat transfer methods can be used to measure wax deposits indirectly without down time (Chen et al., 1997). Zaman et al. (2004) explored alternative methods of measuring wax deposition in pipelines. Firstly, they experimented with measuring light absorption through crude oil using a light source and a detector circuit mounted within a pipe. They found that, in laboratory tests, this detector circuit proved capable of detecting contamination even with a very small percentage present. The use of ultrasound for solid detection, also explored by Zaman et al. (2004) proved very successful in detecting extremely small solid grains. Finally, they were able to use a strain gauge to detect very small changes in pipeline weight associated with wax deposition. However, all of these methods were only tested with small-scale laboratory representations of actual systems. Practical methods for application of these tools to actual subsea pipelines would still need to be designed. Zaman et al. (2006) have also experimented with the use

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