Journal of Petroleum Science and Engineering (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

Injection of non-reacting gas into production pipelines to ease restart pumping of waxy crude oil

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ARTICLE INFO

Keywords:
Restart pressure
Waxy crude oil
Gas-to-oil ratio
Non-Newtonian fluid
Flow assurance

ABSTRACT

Wax deposition in production pipelines causes flow assurance issue due to reduction in flow rate. Gelling of waxy crude oil after subsequent cooling restricts the flow and causes blockage in pipelines, and thus requiring large and costly pumps to restart and regain the steady flow. Nevertheless, the formation of intra-gel voids in the gel was recently reported to ease restart pumping. Further, it is believed that injecting non-reacting gas into the production lines prior to or during shut down could alleviate the restart flow problem and save costs. An experimental work was conducted in order to manipulate the effectiveness of such approach. A flow loop rig was used to simulate the conditions of waxy crude oil in pipelines on seabed and a gas injection system was used to inject nitrogen into the system after crude oil stopped flowing, prior to gelation process. Restart pressure was applied in two modes: instantaneous and gradual pumping. It was observed that maximum restart pressure reductions of 11.48% and 17.44% were achieved when pressure was applied instantaneously and gradually, respectively. It was found that the restart pressure decreased as the gas to oil volume ratio increased due to high slippage effect. In addition, restart pressure under gradual restart approach was observed to be higher than that for instantaneous restart approach.

1. Introduction

Crude oil, being a primary source of energy throughout the world, has provided challenges to oil and gas operators as they need to source for heavier, waxy crude oil and this leads to deeper water depth exploration in oil producing region. Waxy crude oil with a high pour point temperature (PPT) contains high paraffin waxes (alkanes) (Bomba, 1986; Li and Zhang, 2003). Paraffin (wax) deposition over the internal wall of pipelines during the production and processing stage contributes to flow assurance issues (Hammami and Raines, 1999; Carnahan, 2007). This would cost the oil and gas industries millions in order to mitigate pipeline blockage which, according to United States Department of Energy, the cost of remediation for pipeline blockage in water depths of around 400 m can easily reach US $1 million/mile (Venkatesan et al., 2005). Under normal operating temperature, wax is soluble within the waxy crude oil and it exhibits Newtonian liquid properties (Chala et al., 2015a; Modesty et al., 2013). As it is transported within production pipelines, the crude oil temperature falls below its Wax Appearance Temperature (WAT) due to heat loss to the surrounding seabed environment (Aiyejina et al., 2011). In an event of emergency shutdown or planned maintenance, the crude oil stops flowing and quiescent condition causes the temperature of the crude oil and the solubility of the wax to decrease even further, causing the waxy crude oil to drop below its Pour Point Temperature (PPT) (Kasumu et al., 2013). Wax molecules precipitate out of its liquid phase and would cause blockages within production pipelines particularly at below PPT (Lee et al., 2007; Thuc et al., 2003). The deposition of wax is largely dependent on flow rate of the waxy crude oil, temperature difference between crude oil and pipe surface, cooling rate between crude oil and pipe surface and pipeline surface properties (Sanjay et al., 1995).

Once deposition of waxes starts forming at below wax appearance temperature it would then be followed by gelation, which blocks the production lines. In this condition the flow operating pressure is generally not sufficient to displace the gelled waxy crude oil and this requires procurement of pumps with higher than usual head (Ekweribe et al., 2008). The current practice in industry now is that the restart pressure needed to displace the gelled crude oil in production pipelines is estimated by (Margarone et al., 2010):

$$\Delta P = \frac{4\tau_y L}{D} \tag{1}$$

where ΔP, L, D and τ_y are differential pressure applied to break the gel, length of the pipeline, internal diameter of the pipeline and yield stress

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http://dx.doi.org/10.1016/j.petrol.2017.01.046
Received 29 August 2016; Received in revised form 14 January 2017; Accepted 27 January 2017
0920-4105/

of the gel, respectively. Eq. (1) usually yields a conservative restart pressure value although recently this has been reported to be over predicted (Wachs et al., 2009). This can be attributed to the compressibility characteristics of the gelled waxy crude oil that are not included in the conventional equation (Eq. (1)) (Liu et al., 2014). Over predictions of restart pressure and piping parameters as a result of the simplified assumptions made in the conventional equations are also reported elsewhere (Borghi et al., 2003; Phillips et al., 2011).

The presence of local gas voids due to thermal shrinkage that occurs during gelling process of the waxy crude oil has been observed in few works (Hénaut et al., 1999; Chala et al., 2015a, 2015b, 2015c; Shafquet et al., 2015). Vinay et al. (2007) observed that gas voids of within the range of 4–8% volume in the pipe were not unusual under shutdown conditions. A study conducted by Chala et al. (2014) revealed that intra-gel gas voids formation depended not only on the temperature of waxy crude oil but on the cooling rate as well. It was noted that at high cooling rate of 1.01 °C/min, large gas voids was formed near the pipeline's wall and at low cooling rate of 0.45 °C/min, large gas voids were formed around central region of the pipeline.

Detailed studies were also made on voids formation in waxy crude oil along and across pipelines following simulation of waxy crude oil condition at offshore using a flow loop rig (Chala et al., 2015c), in which gas voids of 11.3% in volume were observed. The same authors presented the influence of flow rates on the formation of voids in waxy crude oil under dynamic and static cooling mode (Chala et al., 2015b). Reduction in the volume of gelled crude oil was observed in waxy crude oil gel at below the pour point temperature. The formation of voids would also make the restart pressure smaller than that predicted using the conventional equation due to the negative pressure in the voids. Taking this into consideration, the authors believe that injecting non-reacting gas into production pipelines would ease restart pumping of waxy crude oil. Further, the reduction in pour point of composite fluid due to free gas in the crude oil was reported mainly due to the additional energy of the gas to deform the waxy gelled crude oil (Rai et al., 1996).

At offshore fields involving waxy crude oil, non-reacting gases (in view of risk of explosion) could be injected into pipelines at selected points located along the pipeline prior to or during plant shutdown. This could be useful for production operation especially during emergency shutdown since there would be limited time available to adopt other mitigation approaches. Although there are other methods available to mitigate the problems of the gelation of waxy crude oil, such as use of trace heaters along the pipeline or by circulating hot water or oil in bundled pipeline, the high capital expenditure (CAPEX) and operational expenditure (OPEX) involved become hindrance (Wheeler et al., 1989). Low cost gases such as nitrogen can be made available without much complexity in installation, and thus would be economical. However, the effect of manipulating the intrusion of non-reacting gas on the restart pressure is unclear. Thus, the objective of this study was to investigate the effectiveness of intrusion of non-reacting gas into production lines in easing restart pumping of waxy crude oil.

2. Experimental setup and techniques

Fig. 1 shows schematic diagram of the waxy crude oil flow loop rig used in this work. The waxy crude oil was stored inside a storage tank, which was heated to above the wax appearance temperature to liquefy waxes in the gelled crude oil. A stirrer motor placed on top of the storage tank was used to ensure a homogenous heating and removal of past thermal behavior. The system contained an acrylic test section pipe of 1.2 m in length and 0.03 m in diameter, which was placed in a water bath. The pipings within the systems were rolled with trace heaters all the way except for the test section pipe within the water bath. Both the trace heaters along the pipelines and heater within the storage tank were switched on at the same time. Pipelines upstream and downstream of the test section were heated to 80 °C to liquefy any remaining gelled waxes within the piping and remove shear and thermal histories.

Once the storage tank and piping system were heated up, a gear pump was switched on in order to build enough pressure to disintegrate the gelled crude oil in the acrylic test section. Table 1 shows specification of the gear pump. After the test section had resumed flowing condition, crude oil then returned back to the crude oil storage

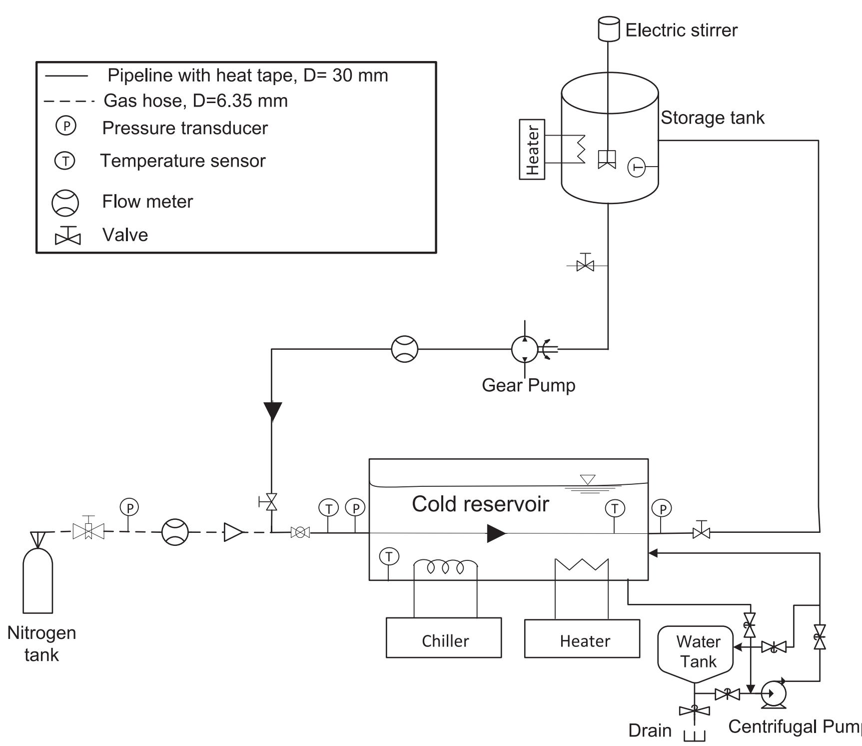

Fig. 1. Schematic of the experimental set up.