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# Measurement and analysis of wax–oil gel scraping process at contact area under pure sliding conditions

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ABSTRACT

Tribological properties of wax–oil gel mixture during gel-scraping process have been experimentally investigated for hard contact based on optical fluorescence. A test facility was designed and adapted to deposit-scraping. A wax–oil gel mixture of commercial wax and white-oil is prepared from different wax-contents. The results indicated that the relative angle ($\lambda$) of outlet region in gel-scraping process increases as sliding speed increases, and the gel-scraping process is dependent on the force balance of wax-deposit. Experimental results also show that presence of higher wax-content increased the complexity of gel-scraping operations. Theoretical models were proposed for analyzing the tribological mechanism in scraping-process.



## 1. Introduction

Offshore dewaxing is the standard industrial process of using several mechanical pipeline inspection gauges (PIG) devices from a vessel for the deepwater pipeline maintenance or inspection [1–6]. Specially, knowledge on the rubbing contact between scraper in PIG and rigid pipewall is of great importance for the better understanding of accurate dewaxing mechanism and pipeline inspection, while the intelligent dewaxing equipment is one of the biggest challenges with the ever-increasing of ultra-deepwater oilfield. Wang et al. [7,8] studied the de-waxing behaviors by flow process design in test pipe-loop, which help improve debris-removal (corrosion products and deposit). Previously, a joint project in Shell Ltd. [9] was set up with the aim of developing a PIG tool that could travel against the oil flow aiming to scrape the inside surface of subsea pipe. Hamid et al. [10] investigated the dynamic involved in dewatering PIG trains and abolishes certain intuitively developed paradigms to minimize the hydraulic transients. Quarini et al. [11] and Haniffa et al. [12] reviewed the fluid-driven in-pipe robots and the different types of PIG devices using in hydrocarbon industries, fluid products and process industries, etc. A significant body of theoretical and experimental efforts has also been directed toward exploring wax-deposition formations, aging effect and waxy crudes [13–15]. Despite these progresses, the question, "what will happen in hard contact-region during the wax–oil gel scraping operations in deepwater pipeline dewaxing maintenances?" has been rarely discussed.

Meanwhile, in a well-established measuring technique known as optical fluorescence, fluorescent dyes have been used as tracers in order to obtain the flow behaviors of complex fluid at contact region in the moving systems. The dynamics of solid–liquid multiphase flow between two rubbing surfaces has attracted much attention over the years. Guo et al. [16,17] measured the movement of nanoparticles in slurry at the glass/PU soft interfacial by the fluorescent technique. Tan et al. [18,19] probed the 'inlet aggregation' phenomenon of wax-debris at the rubber tribology motions, which will still play a role in many practical situations. Myant, Spikes et al. [20–23] measured the nanoscale film thickness in soft contact

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using fluorescent technique, aiming to seal materials, food processing, biotribology, etc. Deleau et al. [24] measured the confined water film at screen wiper. Chavez-Carlos [25] studied the particle ingestion and accumulation in the rotating seal contact. Each application will benefit from a specific result. To the authors' knowledge, the dynamic behaviors of wax–oil gel deposit at sliding hard contact, such as metals, have not yet been investigated and there has been no systematic approach to in situ fluorescent measuring techniques [26–28].

Nevertheless, the tribological behavior of wax–oil gel scraping involves deep scientific puzzles. As being schematically indicated in Fig. 1(a), the dewater pipeline dewaxing is determined by moving system at scraper part (Fig. 1(b)), which is formed between the rigid pipe and different scraper (Fig. 1(e)). Dewaxing in pipeline maintenance or deepwater inspection is not easy to conduct, since the sliding contact region is complex [29–31]. Hence, characterizing the flow property at sliding contact during wax–oil gel scraping has been expected to better understand the fundamental mechanisms in offshore pipeline pigging. In the present work, wax–oil gel scraping process has been investigated using an experimental system aiming at the deepwater pipeline dewaxing.

## 2. Experiment conditions

In this study, a direct observation to the tribological property during wax–oil gel mixture scraping process at hard contact was conducted. The experimental configuration is shown in Fig. 2. The contacting pairs are composed of a precision steel ball (Radius of steel ball $R = 7$ mm, Young's modulus $E = 210$ GPa, Poisson's ratio $\upsilon = 0.28$) and a rigid glass plate ($E = 65$ GPa, $\upsilon = 0.16$). As schematically shown in Fig. 2, the optical window of rigid specimen is a rigid glass plate and without any coating. The size of

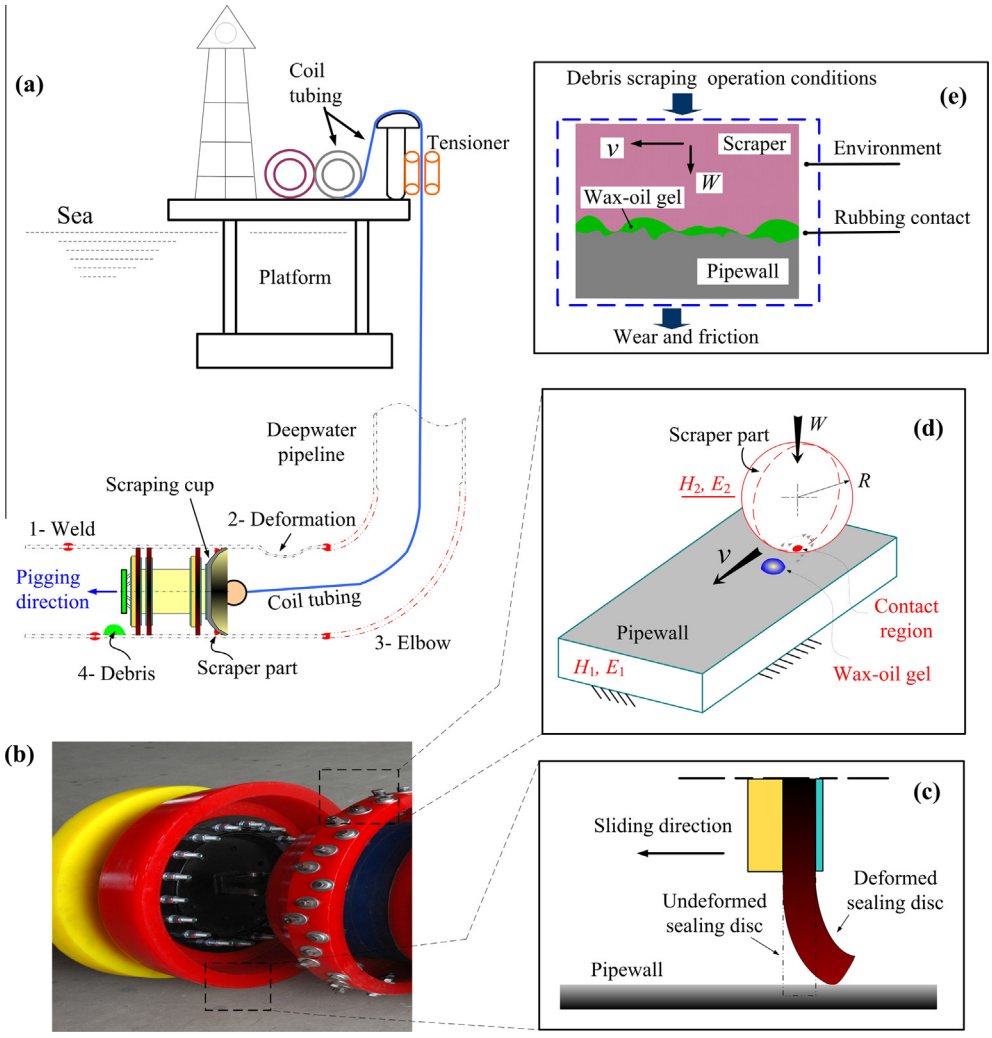


**Fig. 1.** Schematic presentation of the tribological system in offshore de-waxing devices under pure sliding conditions, showing the interaction of the wax-scraper's surface with the rigid steel pipewall, in the presence of a complex wax–oil gel and surround by the environment. (a) Main construction of the PIG devices in de-waxing operations for subsea pipelines, (b) mechanical PIG prototype, (c) rough soft contact of Polymer-to-Metal (PoM) in rubber sealing-cup of dewaxing process, (d) Metal-to-Metal (MoM) hard contact in wax–oil gel scraping process, (e) simple tribological system in wax–oil gel scraping.