energy&fuels

JANUARY 2016
VOLUME 30 ISSUE 1
ENFUEM 30(1) 1–758 (2016)
ISSN 0887-0624
Registered in the U.S. Patent and Trademark Office

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Wax Deposition in the Presence of Suspended Crystals

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Supporting Information

ABSTRACT: Wax deposition in pipelines is one of the most relevant flow assurance problems faced by the petroleum industry. Molecular diffusion of dissolved paraffin has been considered the dominant deposition mechanism in simulation models available in the literature. In case the pipeline operational conditions are such that the fluid temperature is below the wax appearance temperature (WAT), wax crystals could be present in the bulk of the flowing solution and particle deposition mechanism may play a relevant role. In the present research, bench-scale, well-controlled deposition experiments were conducted for laminar channel flow of a solution with an inlet temperature below the WAT, so that wax crystals were available for deposition. In the experiments, visualizations of the deposition process were sought for three distinct heat flux conditions at the channel boundary: negative, zero, and positive heat flux. Detailed information on the temporal and spatial distributions of the wax deposited along the channel walls was obtained for three values of the laminar channel Reynolds number. It was verified that a channel wall cooler than the flowing fluid (the negative heat flux condition) is a necessary condition to produce deposition. For all of the experimental conditions tested, no deposition was verified under zero or positive heat flux boundary conditions. In all cases studied, the deposits measured were significantly thicker than those obtained for similar flow conditions and fluid-to-wall temperature differences but for inlet fluid temperatures above the WAT. The visualization experiments revealed that wax crystals and crystal agglomerates presented trajectories nearly parallel to the channel wall. These crystals and agglomerates were seen to be decelerated and stopped, being incorporated on a thin wax deposit formed at the initial cooling stages.

■ INTRODUCTION

Wax deposition in pipelines has been studied continuously for decades because it is one of the most relevant flow assurance problems faced by the petroleum industry. In subsea petroleum production, the crude oil flows from the reservoir at a relatively high temperature into the production lines. Oil is carried in these pipelines to the platforms and to shore. The temperature of the ocean at large depths can be as low as 5 °C. The solubility of wax in the oil decreases with a decreasing temperature. The oil flowing in the pipelines loses heat to the external ambient water and, if the crude temperature falls below a critical value, wax precipitates from the oil and may deposit on the inner walls of the pipe, causing an increased pressure drop or even the blockage of the pipeline. The ability to predict whether wax deposition will occur in a specific installation is relevant information for pipeline designers and operators. For instance, the indication of a probability of occurrence of deposition will influence the type and amount of thermal insulation to be specified for the pipeline, with direct impact on the cost of the installation. Also, information on the temporal and spatial distributions of the deposit along the line as well as its composition would be useful to guide the strategy of pipeline maintenance, such as selecting pig type and frequency of passage.

Wax deposition simulation models are useful tools to aid pipeline design and operation. Because of the complexity of the phenomena controlling wax deposition, the existing simulation models make use of empirical constants and correction factors that tune the model to a particular set of field data. If, on one hand, this approach produces reasonable results that can be used in studies of the particular field from which the data were obtained, then, on the other hand, it limits the applicability of the model to other fields with different characteristics, because the fundamental physics behind the deposition phenomena is not properly modeled.

Deposition models have also been developed on the basis of fundamental principles, taking into consideration several aspects of the phenomena, such as wax precipitation, crystallization kinetics, convective and diffusive heat and mass transport, and wax removal processes. The prediction of wax precipitation is the first building block of a fundamental wax deposition model. It can be incorporated into the model via experimental solubility curves or through elaborated thermodynamic models. Several thermodynamic models with different degrees of complexity have been developed to predict wax precipitation in petroleum mixtures. Examples of such models are the ideal solid solution model[1] and the multisolid model.[2,3]

Wax precipitation in the flowing oil is a necessary but not sufficient condition for deposition. Transport of paraffin in the liquid or solid phases will determine whether the precipitated paraffin will be driven toward the pipe wall and form solids at the pipe wall or solids that are carried along with the flow without contributing to the formation of the deposit. Several mechanisms have been described in the literature as being potentially responsible for the transport of precipitated wax. A definitive understanding of the relative importance of these mechanisms for different pipeline operating conditions has not

Received: May 14, 2015
Revised: November 26, 2015
Published: November 30, 2015

DOI: 10.1021/acs.energyfuels.5b02344
Energy Fuels 2016, 30, 1−11