Journal of Petroleum Science and Engineering 141 (2016) 70–81

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

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

Modeling and simulation of paraffin solubility in circular pipes in laminar regime flow

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ARTICLE INFO

Article history:
Received 11 July 2015
Received in revised form
18 December 2015
Accepted 18 January 2016
Available online 20 January 2016

Keywords:
Solid–liquid equilibrium
Solubility
Paraffinic wax
Simulation
Finite differences

ABSTRACT

The paraffinic wax deposition of the crude oil reduces pipe's flow area, causing, consequently, larger costs for the oil industry. The solubilization of paraffin using solvents is a viable solution, especially in pipes within treatment plants and oil processing, where use other methods has been restricted, such as the "pig". This paper proposes a method to calculate the paraffin wax solubility in solvent, based on solid–liquid thermodynamic approach for this was proposed a discredited mathematical model for heat and mass transfer. The simplified model is able to successfully reproduce many of the known trends of the paraffin solubility. These models were implemented in programming software, where it was possible to obtain results, as variations in the length of pipe, type of solvent and inlet temperature. The models produced adequate solutions, maintaining continuity of differential energy and mass balance equations, with a viable physical interpretation.

1. Introduction

The formations of paraffinic wax crystals can occur when paraffinic crude oil is subjected to changes in temperature. While the paraffin solubility is strongly dependent on temperature, the pressure does not significantly affect the solubilization in the pipe (Cabanillas, 2006). However, the operating pressure in a wellbore affects paraffinic wax solubility through its effects on solution gas. The gas in solution in the oil it acts to some degree as a solvent for paraffinic wax, the loss of solution gas raises the paraffinic wax crystallization temperature, decreasing the solubility of the paraffinic wax in the oil (Weingarten and Euchner, 1988). In an oil piping, where cooling takes place below the initial temperature of crystal formation, a temperature gradient is established in the radial direction of the pipe, initiating the paraffin crystallization process (Gomes, 2009).

The paraffin crystallization process is closely associated to thermodynamic equilibrium, and is a function of the composition of various fractions that oil make up. Paraffin crystallizes when it is deposited on the inner walls of pipes, reducing the flow area and sometimes resulting in total blockage of the pipe. This significantly increases costs in the oil industry due to production losses, damaged equipment, in addition to elevated operating risks in terms of human and material losses (Haddad et al., 2010). In treatment plants and oil processing with the pipes small length and small diameter, where use the PIG is restricted and unfeasible, the use of solvent is a viable solution.

In all situations, the most efficient way of dealing with this paraffin deposition problem is preventing its occurrence. This requires total control over all the variables involved in the crystallization process. However, given the difficulty in controlling them, the resolution of this problem is not easy. Thus, a number of researchers have investigated different methods and processes capable of inhibiting the deposition of these paraffins. The controlling of the paraffin deposition process involves consolidated operational methods such as when using chemical additives (which modify the shape of the crystals), thermal isolation, and mechanical and chemical solvent removal (Gomes, 2009).

The paraffin deposition mechanism is important for the understand of paraffinic crystal formation conditions and avoiding them in real processes. The deposition process of paraffin has been widely studied in recent decades by countless researchers (Burger et al., 1981; Hunt, 1962; Leiroz and Azevedo, 2005). A number of mechanisms describe the deposition phenomenon such as molecular diffusion, Brownian diffusion, shear dispersion mechanism and gravitational mechanism (Jung et al., 2014). Azevedo and Texeira (2003) conducted a literature review to assess the main models applied to describe paraffin deposition mechanisms. They observed that the molecular diffusion was predominant in most of the models studied, while the gravitational mechanism played no significant role in the paraffin deposition process.

Some deposition prediction models are simple, based on solubilization curves (Gustavo and Sergio, 2006; Ribeiro et al., 1997). In these models, the flow profile is considered parabolic, one-dimensional and

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http://dx.doi.org/10.1016/j.petrol.2016.01.026
0920-4105/

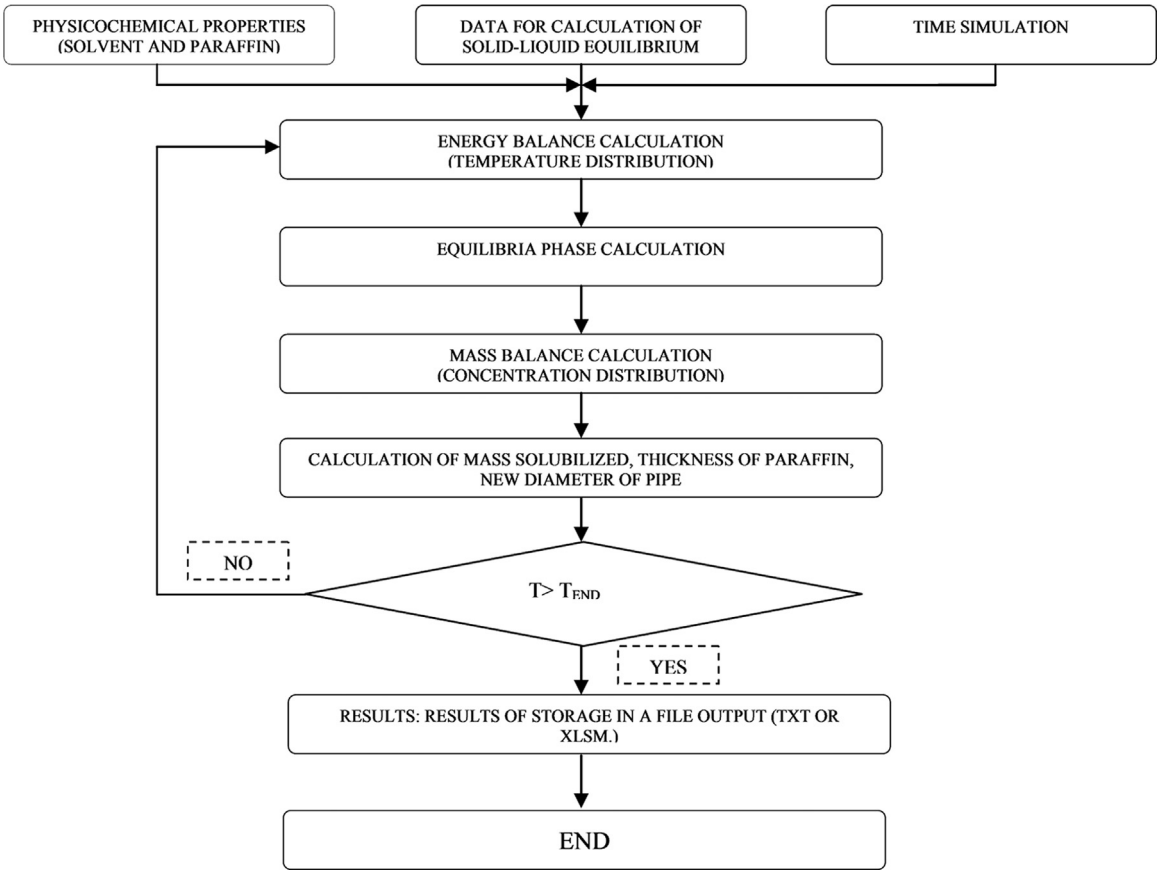

Fig. 1. Computational algorithm of the process solubilization.

Table 1
Parameters used in simulations.

Operating conditions	Parameters		
	Pipe length	Solvent type	Solvent temperature
Inlet temperature (K)	318.15	318.15	**428.15–318.15**
Ambient temperature (K)	298.15	298.15	298.15
Solvent type	Hexane	**Hexane–kerosene**	Kerosene
Flow (m^3/h)	0.21	0.10	0.10
Pipe diameter	4 in-SCH 40	2 in-SCH 40	2 in-SCH 40
Pipe Length (m)	**10–50**	10	10
Paraffin molar mass (g/mol)	394	394	394
Pipe thermal conductivity (W/mK)	48	48	48
Operation time (min)	2250	1000	3000
Profile display interval (min)	450	200	600

Table 2
Physicochemical properties of the solvents (hexane and kerosene) and paraffin used in the simulations.[a]

	Hexane	*Kerosene*	*Paraffin*
Molecular mass (g/mol)	86.17	184	394
Viscosity (cP)	0.238	2.25	–
Specific mass (kg/m^3)	633.36	800	900
Conductivity (W/m K)	0.1074	0.1341	0.2596
Heat capacity (kJ/kg K)	2.316	2.125	–

[a] *Source*: Databank of the Hysys V.3.0.1 simulator (Build 4602) (Hyprotech Ltd.).

under steady state, and only the molecular diffusion mechanism is present. Also using only the molecular diffusion model, Romero (2005) compared his models with experimental data obtained by Leiroz (2004), in which good agreement was observed when flow was in a permanent regime, although the same did not occur in the transient regime. Ramirez-Jaramillo et al. (2004) modeled the wax paraffin deposition in oil pipelines considering mathematical models with molecular diffusion mechanisms in radial coordinates and flow-induced shear removal.

Given that solubility process is the inverse deposition process, the aim of this study was to develop a calculation method that represents the paraffin solubility in paraffinic solvents, based on phenomenon of mass transfer, energy transfer and solid–liquid equilibrium, proposed for the deposition process. Furthermore, also were evaluated concentration, temperature and solubilization profiles through these models, as well as better flow and operating conditions in the solubilization process.

2. Mathematical modeling

Modeling of the paraffin solubility process consists of three phenomena: energy and mass transfer, solid–liquid equilibrium. Based on works by Araújo (2008), Ramirez-Jaramillo et al. (2004) and Singh et al. (2000), the following assumptions were made: (i) velocity profile developed at each time interval which assumes the solid–liquid interface moves slowly over time analyzed, consequently the mass and energy balance could be considered as a quasi-stationary model in the paraffin solubility process; (ii) in a laminar regime, the shear removal rate was disregarded using only molecular diffusion; (iii) supposing the quasi-stationary regime, heat transfer in the axial direction occurs almost instantaneously,