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Architectonic Enhancement Of A Flow Enhancer Diffusion For Crude Oil Transportation

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***Abstract*— Heavy and extra-heavy crude oils transportation is one of the target issues to solve in the petroleum industry. The high viscosity of these kinds of fluids requires solutions like the addition of flow enhancers. The effectiveness of such chemical products is mainly due to the form in which they are added to the pipelines. In this work, the enhancement of the diffusion of a methyl ester derivative (biodiesel) acting as a viscosity reducer is studied under the premise that the heated pre-mixing of the crude and the enhancer would improve the diffusion of the chemical product in the stream of crude. A mathematical model is presented that shows a good prediction of the effectiveness of the addition process proposed.**

Keywords—Crude oil transportation; diffusion of liquid/liquid mixture; heated pre-mixing addition

I. Introduction

Crude oil is formed by a complex mixture of hydrocarbons which belong to a series of molecules with a wide range of molecular weight. Experimentally, as the molecular weight and complexity of the chemical structure are increased, the viscosity of the crude oil increases as well [1]. Viscosity is an important property from which the movement of a liquid can be predicted [2].

There are two basic procedures to decrease the viscosity of heavy and extra-heavy crude oils: increasing temperature of the system [3] and adding chemical products (viscosity reducers) [4].

From the mathematical models that describe the diffusion phenomena, considering the viscosity of the fluid, in this work a model to predict the diffusion process of a chemical product constituted by the methyl ester derivatives of the fatty acids of an oil obtained from biomass (biodiesel) acting as a flow enhancer is presented. The proposed model was adjusted with respect to the experimental results and it is used to show the effect of the pre-mixing of the components and temperature on the diffusivity when the biodiesel is mixed with the crude oil.

II. Development of the Model

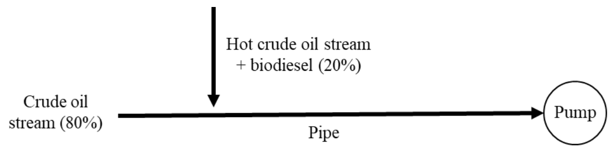

Fig. 1. *Schematization of a horizontal duct (z-axis) and the point of injection of the biodiesel to achieve pre-mixing.*

The transport change equations for the component A (related to the biodiesel as a viscosity reducer) through the fluid B (corresponding to crude oil) are as follow [5]:

$$c\left(\frac{\partial x_A}{\partial t} + v_r^* \frac{\partial x_A}{\partial r} + \frac{v_\theta^*}{r}\frac{\partial x_A}{\partial \theta} + v_z^* \frac{\partial x_A}{\partial z}\right) = cD_{AB}\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial x_A}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 x_A}{\partial \theta^2} + \frac{\partial^2 x_A}{\partial z^2}\right] + R_A - x_A \sum_B R_B \quad (1)$$

where D_{AB} represents the enhancer diffusivity, x the enhancer concentration, z the length of the pipe, and R_A and R_B the point of entrance of the enhancer and the crude, respectively. This equation is simplified as the regime is considered laminar which means that the crude oil moves on with a mean velocity on z direction, so that the transport occurs along with the fluid movement. It is also established that the addition of the biodiesel is achieved as the following scheme proposed:

From these considerations, the transport of the biodiesel by convection, dx_A/dz, is correlated with the transport by diffusion and with the incoming point:

$$\frac{dx_A}{dz} = \frac{D}{v_z}\frac{d^2x_A}{dz^2} + \frac{R_A}{v_z} = a\frac{d^2x_A}{dz^2} + b \quad (2)$$

The boundary conditions for (2) are defined as:

$$x_A = x_1 : z = 0$$
$$\frac{dx_A}{dz} = 0 : z = L \quad (3)$$

The exact solution of the differential equation is:

$$x_A(z) = C_2 e^{\frac{1}{a}z} - C_1 + ab + bz \quad (4)$$

And the integration constants:

$$C_1 = ab - x_1 + bz - a\frac{b}{e^{\frac{1}{a}}}$$
$$C_2 = -a\frac{b}{e^{\frac{1}{a}}} \quad (5)$$

Substituting in the solution, the behavior of the biodiesel concentration with respect to the pipe length is:

$$x_A(z) = x_1 + abe^{-\frac{1}{a}} - abe^{-\frac{1}{a}}e^{-\frac{1}{a}z} \quad a = \frac{D_{AB}}{v_z} \quad b = \frac{R_A}{v_z} \tag{6}$$

III. Experimental and Results

Among the empirical methods to determine the diffusivity, it is found the one based on the corresponding states law [6], where diffusivity, $D_r=D/D_c$, is obtained from the reduced pressure, $P_r=P/P_c$ (atm), and reduced temperature, $T_r=T/T_c$ (K), where the critical parameters for binary mixtures are determined by the following correlations:

$$P_c = \sqrt{P_{cA}P_{cB}} \quad T_c = \sqrt{T_{cA}T_{cB}} \tag{7}$$

$$\rho(D_{cAB}) = 2.96x10^{-6}\left(\frac{1}{M_A}+\frac{1}{M_B}\right)^{\frac{1}{2}} P_c^{\frac{1}{3}} T_c^{\frac{1}{3}} \tag{8}$$

In (8), ρ is the apparent density of the mixture (gcm^{-3}) and D_{cAB} (cm^{2}s^{-1}) is the critical diffusivity for a specific content of the components M_A and M_B (g)

The diffusivity can also be predicted by theoretical methods, for example, Chapman and Enskog [7] obtained a similar expression for the determination of viscosity and thermal conductivity through the application of kinetic theory and molecular interactions. However, the reported equations are only applicable to pure compounds. In the case of liquids and their mixtures, the kinetic theory has not been fully developed to present accurate analytical models for diffusivity, and until now the most appropriate methods are based on empirical correlations.

The most recommended empirical method is the presented by Wilke-Chang [8], and it is valid for small ratios A/B:

$$D_{AB} = 7.4x10^{-8}\frac{\sqrt{\Psi_B M_B}}{\mu(\tilde{V}_A)^{0.6}}T \tag{9}$$

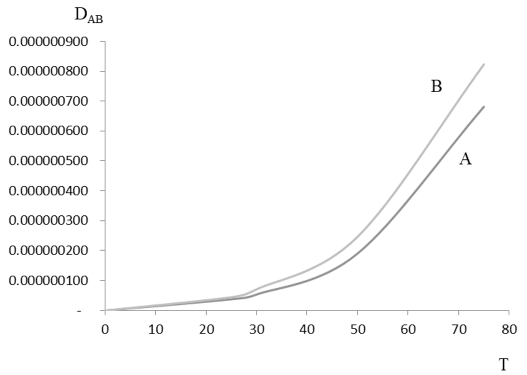

Fig. 2. *Diffusivity behavior of biodiesel in crude oil at (A) 0.5% and (B) 1% with respect to the temperature.*

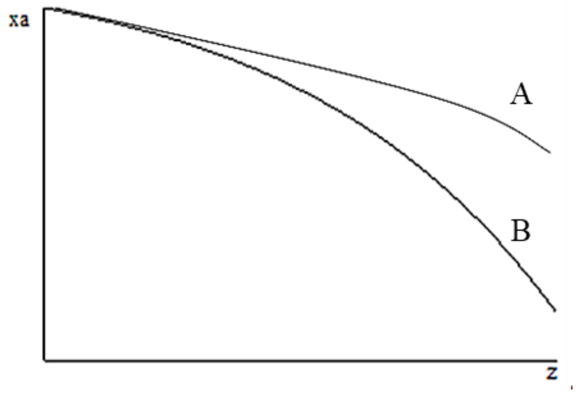

Fig. 3. *Diffusion of biodiesel through z-axis (tube length) with no pre-mixing (A) and with heated pre-mixing (B).*

where D_{AB} (cm^{2}s^{-1}) represents the diffusivity of A in B, $\tilde{V}_A$ (cm^{3}mol) is the molar volume of the liquid A (solute) in the normal boiling point, μ (cP) is the solution viscosity, and Ψ_B is the association parameter of the liquid B (solvent).

In this work the Wilke-Chang correlation was applied for the temperatures 0, 25, 30, 50, and 75 °C and the characteristics of a crude oil from the northern of Mexico reported in [9] by Suárez-Domínguez et al. The diffusivity behavior with respect to the temperature is shown in Fig. 2.

From the experimental data, the qualitative behavior of the equation (6) for 1% of biodiesel and T=0°C for the no premixing process and T=50°C with premixing of the mixture was obtained and is shown in Fig. 3.

IV. Conclusions

As expected, the temperature has a positive effect on the diffusivity of the enhancer under study and this result was the guideline to establish the applicability of the model proposed in (6) which predicts the diffusion behavior of a flow enhancer in crude oil. The model describes the effectiveness of the heated pre-mixing of both biodiesel and crude oil when it is injected before the pumping system.

According to the results, for longer distances of the point of injection on the pipe the diffusion of the enhancer is increased, and it is higher for the heated pre-mixing, therefore there is a direct correlation between the point of injection, the temperature of the pre-mixed fluid and the diffusion of the enhancer in the crude oil stream. In this sense, the effect of the flow enhancer on viscosity reduction would be improved as a result of the better diffusion process.

Acknowledgments

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