Modeling and Optimization of Wax Deposition Based on Response Surface Methodology and Simulation Using Aspen HYSYS.

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Abstract

This work aims to study the effect wax deposition process parameters during crude oil transportation process. Mathematical model and optimization parameters of the wax deposition are introduced. Aspen HYSYS software were utilized to simulate the experiments and to calculate the wax deposition for each designed experiment. The wax deposition values were carried out according to the central composite experimental design (CCD) as a response using Minitab 16 software and used to design the experiments. The conformity of the obtained mathematical model was carried out by means of calculating the Mean square error. This error was 0.00002 which showed a good consistency of the obtained mathematical model. The optimal wax deposition conditions were determined, temperature (54°C), pressure (20 bar), molar flow (975 kg. mole/h), and the time is for 1week. Accordingly, the minimum wax deposition is 12.3 mm.

Keywords: Wax deposition, Modeling, Prediction, Response surface methodology.

الملخص

هذا العمل يهدف الى دراسة تأثير متغيرات التشغيل لعملية ترسب الشمع خلال عملية نقل النفط الخام. حيث تم تقديم نموذجا رياضيا و تم تحديد هذه المتغيرات. استخدمت برمجية الاسبن هايسز, لمحاكاة التجارب التي صممت بطريقة الاستجابة السطحية نوع التصميم المركزي المركب ببرمجية المني تاب 16, لحساب قيم ترسب الشمع. وللتأكيد من النموذج الرياضي تم حساب قيم متوسط مربعات الخطأ و كانت قيمته 0.00002 و الذي يشير الي تطابق القيم

الناتجة منه. كما تم تحديد القيم المثلى للمتغيرات المؤثرة علي ترسب الشمع, التي درست في هذا البحث, وكانت قيمها 45 درجة مئوية للحرارة, 20 بار للضغط و 975 كجم/ مول-ساعة لتدفق المولات. حيث درس هذا الترسب خلال اسبوع و كانت قيمة ترسب الشمع عند هذه المتغيرات 12.3 مم.

1. Introduction.

Wax deposition is one of the problems encountered in the petroleum industry which can be attributed to a decrease in pressure and/or temperature. A decrease in Pressure cause loss of light and components which serves as natural solvents for the waxes and a decreased temperature, which affects the solubility of wax in crude oil (Salam, K. et al, 2004).

Figure 1 shows the wax deposition problems in the pipeline that prevents crude oil from passing through the pipe (Theyab et al, 2018). Crude oil transportation in the pipelines at cold environment is affected by the low temperature causing a problem such as wax deposition. The flow assurance in the hydrocarbon pipelines is very important due to the precipitation of the solid phase of wax on the pipe wall, creating pressure abnormalities and causing an artificial blockage leading to a reduction or interruption in the production. Wax can precipitate as a solid phase on the pipe wall when its temperature (inlet coolant temperature) drops below the wax appearance temperature (WAT) (Theyab, A., M, 2018).

When the temperature of crude oil drops as it occurs in the production tubing of oil wells and pipelines, the solubility of the heavy fractions may be sufficiently reduced to cause precipitation of solid particles of wax and asphaltenes. Two types of wax are commonly encountered in crude oils. The first is the microcrystalline wax composed of mainly straight-chain paraffin's (n-alkanes) with varying chain length (about C20– C50). The second is the microcrystalline or amorphous waxes containing a high portion of isoparaffins (Elsharkawy et al, 2000) Cycloalkanes and Naphthenes with a molecular weight range from C30 to C60.

Figure.1. Wax deposition plug in the wellbore on platform C in the North Sea (Theyab et al, 2018).

Successful wax deposition management will become more important to the future because new explorations and productions are being made farther offshore. The wax deposition management cost to the petroleum production industry is enormous and will increase both in terms of capital costs (e.g. preventive methods) and operating costs (e.g. Corrective methods). (Theyab, A., et al , 2018).

Recently, three technologies are used around the world to mitigate wax deposition in offshore and onshore oil. Namely, pigging, thermal mitigation, and wax inhibitors (chemical inhibitors). Most of the oil companies are using the wax inhibitors, as a main mitigation method to reduce wax, combined with pigging or thermal insulation (Theyab, et al, 2018).

Therefore, it is essential to be able to predict the amount and conditions of wax precipitation in order to reduce operating expenses. Various experimental studies have been carried out to simulate the wax sedimentation process laboratory (Salam et al., 2014) Wax deposition in different crude oil pipeline systems were studied and reported in. In oil pipelines, the main mechanism for wax appearance was the temperature change along the pipeline. A computer program was developed to simulate the wax precipitation phenomena. Temperature profile along the pipeline, solid liquid equilibrium constant, wax mole fraction, and wax thicknessalong the pipeline were calculated. The computer program was applied to different crude oil pipeline systems in Iraq (Baiji-Daura, Rumaila-Zubair-Fao and Haditha-

Rumailia). In Haditha-Rumaila crude oil pipeline system, it was observed that wax thickness after a year was approximately 0.1 mm and temperature declined from 303 K to around 300.5 K. The wax mole fraction after a year was approximately 0.2. The solid-liquid equilibrium constant for the first component was around 0.228 and around 165 for the second component after a year. Similar results were observed in other crude oil pipeline systems studied.

(Ridzuan et al., 2016) the application of response surface method designed based on the rotatable central composite design (CCD) was used to optimize wax deposit using Design Expert 7.1.6 Software and was reported. The process consisted of 13 experiments involving eight factorial points and five replications at the center point. The influence of operating parameters on the weight of wax deposit was investigated using cold finger apparatus. The experimental result indicated that the amount of wax deposit was significant due to factors of cold finger temperature and experimental duration. The wax deposit amount decreased significantly with the decrease of experimental duration when the cold finger temperature increased to 25 °C. The minimum value of 0.0042 g of wax deposit was obtained at the optimized conditions of 1.5 hours and 25 °C, respectively.

(Almeslati, F., & Tarrum, E, 2016) Wax crystals lead to oil high viscosity and decreased pumping capacity. A research work aimed to investigating wax deposition in flow lines. This may include; effect of oil ambient temperature, insulation thickness and, time duration on wax deposition rate in the pipeline. Two computer software HYSYS and PVTSIM were used to estimate wax deposition. The obtained results show that wax deposition can be predicted with good accuracy with computer software.

(Theyab et al., 2018) an ideal design of oil pipelines should use an accurate mathematical model that would include all salient features of wax deposition and waxy crude transport to predict wax deposition during crude oil transportation. In an article, a comprehensive mathematical model, both in laminar and turbulent flow regimes, was developed. The model couple's energy equation with deposition and removal kinetics model and thermodynamic model. The $k-\varepsilon$ turbulent flow model and energy equation were used to predict velocity and temperature distributions in the turbulent flow regime. Molecular diffusion of wax, as a mechanism of deposition and sloughing effect due to the hydrodynamic forces of fluid on deposited wax, had been considered.

Parametric studies on the variation of the amount of wax deposition were performed for a mixtureof toluene and oil wax cut in an experimental setup. The overall predictive ability of the proposed model was excellent for the laminar flow. For the turbulent flow regime, no necessary complete experimental data into the model were available. Consequently, qualitative results were presented and discussed.

2. Materials.

The Messla – Tobruk pipeline transports crude oil from Messla field in the South East of the Libyan Sahara Desert to the Tobruk terminal in the East of the Libyan coast. Data used for the current study were recorded in 1/11/2008 by the technical affairs department-process engineering section.

3. Methods.

Experimental Design (ED) and Response Surface Methodology (RSM) are used for uncertainty quantification of production forecast during resource evaluation of petroleum fields. Considering all uncertainty for analysis can be time consuming and expensive. The central composite design will be considered in this study. Table 1 presents monitoring data of Messla -Tobruk main oilline and process parameters.

Table 1. Experimental ranges in terms of uncertain parameters

No.	Parameters	Notation	Unit	Range	
				Lower value	Upper value
1	Temperature	T	^oC	36	54
2	Pressure	P	Bar	20	30
3	Molar Flow	MF	Kg.mole/h	650	975

The parameter's values were manipulated within (+ and -) 20% to investigate theireffect on the wax deposition. This percentage was used since within this percentagerange, the wax deposition is highly affected.

4. Results and Discussion.

Aspen HYSYS is a user-friendly process simulator and over the years its demand is increasing rapidly in various industrial and educational zone. It was utilized to calculate the wax deposition for each experiments designed by CCD approach.

The mathematical model is obtained as shown in equation (1) and used to predict the wax deposition. The experiment run, the actual simulated values given by Aspen HYSYS and predicted values of Wax Deposition (WD) given the mathematical model are shown in Table 2.

Table 2. The experiment run, the calculated and predicted wax deposition

Run	T(^{o}C)	P(bar)	MF (kg.mole/h)	Actual WD (mm)	Predicted WD (mm)
1	36	20	975	12.43	12.4042
2	45	25	812.5	12.51	12.49184
3	36	20	650	12.39	12.4022
4	45	20	812.5	12.51	12.5373
5	36	30	650	12.39	12.4022
6	45	25	812.5	12.51	12.49184
7	54	20	975	12.3	12.27421
8	36	30	975	12.43	12.4042
9	54	30	975	12.3	12.27421
10	36	25	812.5	12.41	12.43729
11	45	25	975	12.3	12.4033
12	45	25	650	12.47	12.42129
13	45	25	812.5	12.51	12.49184
14	45	25	812.5	12.51	12.49184
15	54	25	812.5	12.3	12.3273
16	45	25	812.5	12.51	12.49184
17	54	20	650	12.3	12.31221
18	45	25	812.5	12.51	12.49184
19	54	30	650	12.3	12.31221
20	45	30	812.5	12.51	12.53729

Minitab software was also utilized to investigate the process parameters and to determine estimate regression coefficient. Table 3 shows estimated regression coefficient and the p-values that determine whether the effects are significant orinsignificant.

Table 3. The estimated regression coefficient for wax deposition

Term	Coefficient	SE	T-Value	P-value	
Constant	12.4918	15.85×10^{-3}	788.111	0.0	Significant
T(ºC)	-0.0550	14.58×10^{-3}	-3.772	0.004	Significant
P(bar)	-0.0	14.58×10^{-3}	-0.0	1.0	Insignificant
MF (kg.mole/h)	-0.009	14.58×10^{-3}	-0.617	0.551	Insignificant
T(ºC)* T(ºC)	-0.1095	0.0278	-3.94	0.003	Significant
P(bar)*P(bar)	0.0455	0.0278	1.635	0.133	Insignificant
MF(kgmole/h)*MF(kgmole/h)	-0.0795	0.0278	-2.861	0.017	Significant
T(ºC)*P(bar)	-0.0	0.0163	-0.0	1.0	Insignificant
T(ºC)*MF(kgmole/h)	-0.01	0.0163	-0.613	0.553	Insignificant
P(bar)*MF(kgmole/h)	-0.0	0.0163	-0.0	1.0	Insignificant

The equation from the table of estimated regression coefficients for wax deposition (mm)of the first – second order is given as equation 1:

$$WD = 8.97091 + 0.121162\,T - 0.0909091\,P + 0.00514741\,MF - 0.00135241\,(T*T) + 0.00181818\,(P*P) - 3.01237*10^{-6}*(MF*MF) - 1.33283*10^{-19}\,(T*P) - 6.83761*10^{-6}\,(T*MF) - 1.10714*10^{-21}\,(P*MF) \quad (1)$$

Where:

WD: Wax Deposition (mm), T: Temperature (ºC), P: Pressure (bar), and MF: Molar flow (kg.mole/h)

a. Model Validation.

To validate the developed model, the standard error was used to estimate the variation between the actual and predicted WD values. The value of the MAE is 0.00002. The scatter plot of actual wax and predicted wax is shown below. It shows a straight line with 45º so this model is excellent for prediction wax deposition.

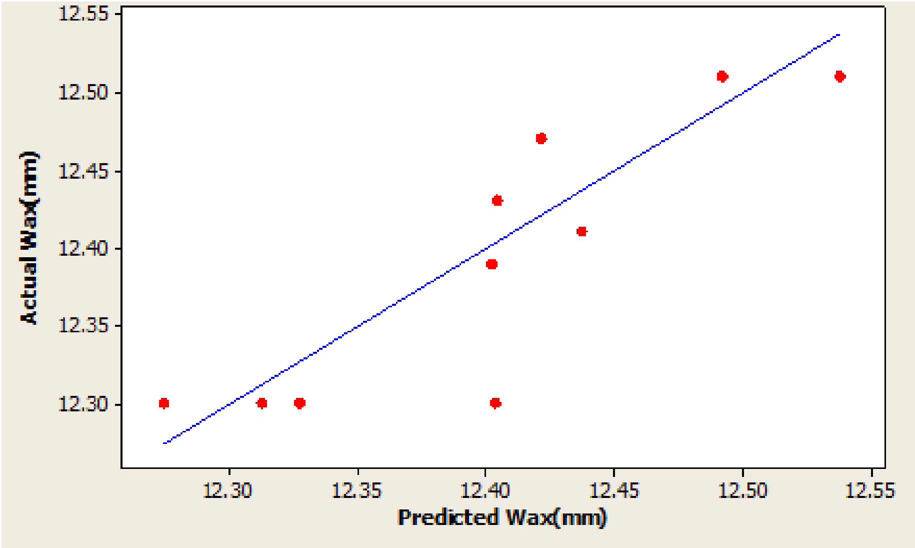

Figure 2. T h e a ctual wax deposition vs. the predicted wax deposition

b. Optimization of Wax Deposition.

Figures 3 through figure 5 show the counter plots of the wax deposition verses the temperature and the pressure, the pressure and the molar flow, the temperature and molar flow respectively. In each figure the third input parameter is kept constant at its mid value. The dark zones in each represent the parameters within which the wax deposition is maximum.

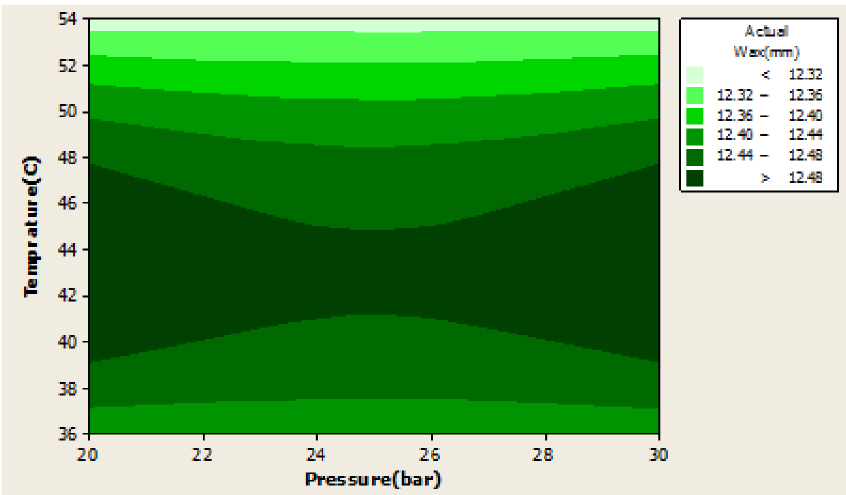

Figure 3. The contour plots of crude oil actual Wax deposition processes vs temperature and pressure

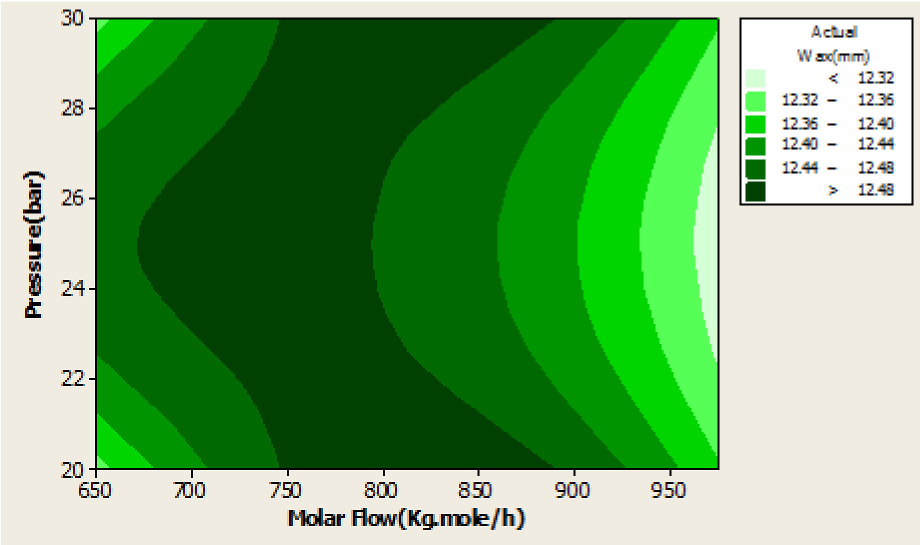

Figure 4. The contour plots of crude oil actual Wax deposition processes vs pressure and molar flow

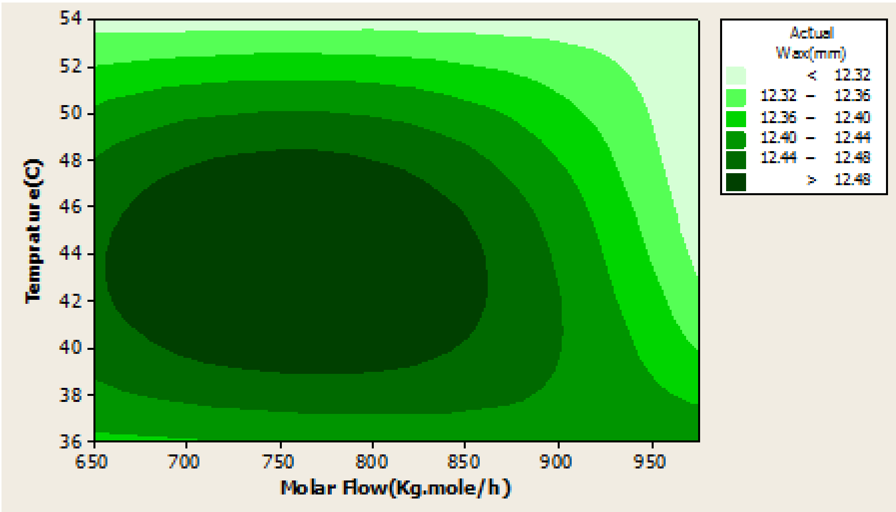

Figure 5. The contour plots of crude oil actual Wax deposition processes vs temperature and molar flow

5. Conclusions.

In this work, attempts were done to predict the wax deposition of the pipelines that are used for transporting the crude oil between Messla-Tobruk stations. The wax deposition values were measured by using Aspen HYSYS V9 software. The theory and principles of wax were also explained.

The following points summarizes the conclusions of the study:

1. Based on the analysis, the temperature had a significant effect on wax deposition

while the pressure, and molar flow were insignificant. However, the interaction between (molar flow and molar flow) is significant, the other interaction such as (temperature and molar flow) and (pressure and molar flow), had no significant effect on wax deposition.

2. Based on the comparison between the actual values of wax deposition calculated by using Aspen HYSYS software and the predicted values of wax deposition by mathematical model, it can be concluded that the mathematical model could be used to predict the values of wax deposition under the specified parameters ranges with a mean square error of 0.00002.

3. The optimal value for the numerically calculated wax deposition using the RSM model was found to be 12.3 mm / week and the values of the corresponding values of temperature is 54°C, the pressure is 20 bar and the molar flow is 975 kg.mole/h.

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