ORIGINAL ARTICLE

DOI: https://doi.org/10.18599/grs.2020.4.86-92 Russian Original 2020. Vol. 22. Is. 4. Pp. 86–92

Modeling and prediction of asphaltene-resin-paraffinic substances deposits in oil production wells

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Abstract. In the oil industry today, the issue of combating deposits of asphaltene-resin-paraffinic substances (ARPD) remains relevant. At the moment, the most common method in the Perm Territory for removing ARPD in wells operated by electric centrifugal pumps is mechanized (mechanical dewaxing units). This method is the main one in the fight against wax deposits, but does not provide absolute protection. The least costly way to deal with ARPD is the use of flushing with hot oil or water, but this also does not always provide sufficient efficiency. The effectiveness of technologies will depend on the depth of deposition, the intensity and thickness of the formed layer of paraffin deposits, respectively, to select an effective technology for each specific well, knowledge of these parameters is required. To solve this problem, computational hydraulic models were created, hydrodynamic modeling and simulation of paraffin deposits when lifting fluid in a well was carried out using the example of five wells of one of the oil fields of the Perm Territory. Based on the calculations, recommendations were given on the choice of the method for removing and preventing ARPD for the analyzed wells. The proposed measures have been implemented at the wells and to date have led to a reduction in the costs of their implementation and significantly reduced oil shortages. In three wells, the change in annular pressure led to a decrease in foaming and stabilization of the dynamic level, while the main problem was solved – ARPDs are not formed in the annulus.

Keywords: software product "OLGA", paraffin layer thickness, dynamic level, bottomhole pressure, depth of paraffin deposition, interclean period, mechanical cleaning method

Recommended citation: Martyushev D.A. (2020). Modeling and prediction of asphaltene-resin-paraffinic substances deposits in oil production wells. *Georesursy = Georesources*, 22(4), pp. 86–92. DOI: https://doi.org/10.18599/grs.2020.4.86-92

Introduction

In the oil industry, the issue of combating asphalt-resin-paraffin deposits (ARPD) remains relevant at the moment (Matiev et al., 2016). In the fields of the Perm Territory, more than 3200 wells are complicated due to intensive paraffin deposition, and in most of the well workovers are carried out for this reason. At the moment, to remove ARPD in wells operated by electric centrifugal pumps (ESP), in the Perm Territory, the most common method is used – mechanized (mechanical dewaxing units (MDU)). The frequency of tripping operations is usually selected based on production experience. This method is the main one in the fight against wax deposits, but does not provide absolute protection (Syuzev et al., 2018). The mechanized method of cleaning from ARPD should be combined with other measures (for example, flushing), as stated in the works (Griselda Garcia-Olvera et al., 2016; Syuzev et al., 2018; Ilyushin et al., 2018; Daiwei Lui et al., 2019; Jaber Azizi et al., 2019; Sousaa et al., 2020).

The least costly way to deal with ARPD is the use of flushing with hot oil (HOF) or water (HWF), but efficiency is not always ensured, since injection is carried out into the annulus and the fluid temperature is sufficient to warm up the tubing to a depth 400 m above the melting point of paraffin, which averages 60°C (for oil fields in the Perm Territory), the rest of the tubing is not heated enough to initiate the melting of paraffin on the wall (Sara M. Hashmi et al., 2013; Vyatkin et al., 2015; Virstiuk et al., 2020; Fahad I Syed et al., 2019, 2020). When flushing with hydrocarbon solvents (HCF), it is necessary to push the reagent into the tubing string above the beginning of wax deposition and maintain the time for the reaction to proceed or flush through the circulation, otherwise the efficiency of HCF application is significantly reduced (Vyatkin et al., 2015; Syuzev et al., 2018; Akberova, 2019).

Accordingly, for the selection of an effective technology for each specific well (it should be noted that even at one field (object) the intensity and depth of wax deposition can differ significantly), it is necessary to know the depth of wax deposition, the intensity and thickness of the formed layer (Cheshkova et al., 2018; Zeeshan Rashid et al., 2019; Mohamed Mehana et al., 2019; Han Zhao et al., 2021; Ali Piroozian et al., 2021).

To solve this urgent problem, it is necessary to use modern means that can assess and predict the depth, intensity and thickness of the deposited paraffin (Fatykhov et al., 2018; Antipenko et al., 2018; Zlobin, 2018; Denisson Santos et al., 2019; Amin Tirjoo et al., 2019; Ce Zheng et al., 2019).

In this work, on the example of five wells of one of the oil fields (terrigenous object) of the Perm Territory, the intensity of paraffin deposition is estimated using the OLGA software package. To solve the indicated problem, data on downhole equipment and well operation modes were collected and systematized; simulation of PVT properties based on compositional composition of well fluids in PVTsim; computational hydraulic models were created and hydrodynamic modeling was carried out in the OLGA software package of paraffin deposits when lifting fluid in a well; recommendations for combating wax deposits and measures to prevent its intensive deposition were formed.

Modeling PVT (pressure, volume and temperature) fluid properties based on composition

The fractional composition of oil samples was carried out according to the ASTM 7213 standard using gas chromatography by the SimDis method. Laboratory studies were carried out in the following order:

1. Preparation of samples for analysis. The oil sample was completely dehydrated. Oil dehydration was carried out in two stages: settling during heating and removal of residual water using calcium chloride.

2. Distillation of the sample. Distillation of oil samples was carried out to remove high-boiling components (above 600°C) for the purpose of further investigation by the chromatographic method (designed for petroleum products with a boiling point of no more than 600°C).

3. Determination of the fractional composition. A sample of each oil sample was used, separated by distillation into two fractions: a distillate distilled off under atmospheric pressure and a residue boiling above 300°C. The distillation results are shown in Table 1.

4. Determination of the component composition. Using the calibration table, the component composition of the samples under study was calculated from the boiling point values. PVTsim software product contains tables of PVT properties. Table 2 shows the component compositions of the studied oil samples. The composition of associated petroleum gas (APG)

Well	Mass of distillate, g	Temperature of end boiling point, °C	Mass of residue, g
1	53	583.2	45
2	50	578.4	48
3	49	595.0	49
4	43	595.6	56
5	49	611.4	49

Tab. 1. Results of distillation of oil samples from analyzed wells

with a single-stage degassing was taken from the design and technical documentation for the development of the field.

Laboratory research of emulsions

Rheological studies of oil-water emulsions from wells were carried out at the current water cut. Dynamic viscosity measurements were carried out on a Rheotest RN 4.1 rotational viscometer. Table 3 shows the results of rheological studies of oil-water emulsions from the analyzed wells.

Creation of computational hydraulic models of wells

The following information was used to create computational models for each well: directional survey; well design; perforation interval; parameters of tubing string and pumping equipment; reservoir properties: pressure, temperature, productivity (Tables 4, 5). The composition and technical parameters of the underground equipment were set in accordance with the certificate of wells. The parameters and hydraulic characteristics of the pumping equipment were taken from the operating certificates for the installation of electric centrifugal pumps. The properties of the layers were set based on the results of interpretation of the data of hydrodynamic studies of wells. Hydraulic calculations were carried out using the obtained data on the composition of the fluid, created on the basis of the compositional composition of oil samples from wells and associated petroleum gas with a single degassing.

To simulate the processes that occur in the wells, the PIPESIM multiphase flow simulator was used, implemented in the OLGA software package. The ability to accurately simulate various scenarios and conditions has made PIPESIM the industry leader in steady-state multiphase flow simulation. To simulate the processes of wax deposition in the well, the models of wax and asphaltene deposition were used, which are implemented in the Multiflash PVT package.

Figure 1 shows the results of hydrodynamic calculations in the form of graphs of the distribution of fluid flow rate, pressure and temperature along the tubing length of wells 3 and 4. The calculations included the bottomhole pressure, the pressure at the pump intake and the dynamic level in the well (Table 6).

Component	Well 1		Well 2		Well 3		Well 4		Well 5	
C5	1.11*	1.13**	1.00	1.02	0.88	0.90	0.73	0.74	-	-
C6	1.61	1.64	1.29	1.32	1.48	1.51	0.85	0.85	1.22	1.24
C7	6.88	7.02	4.61	4.71	5.75	5.86	4.30	4.35	3.84	3.92
C8	11.31	11.54	9.71	9.91	10.02	10.22	9.31	9.40	7.69	7.84
C9	10.49	10.71	9.42	9.61	8.49	8.66	7.70	7.78	8.72	8.90
C10	8.27	8.44	8.08	8.24	7.46	7.61	6.53	6.60	7.63	7.79
C11	6.54	6.68	6.35	6.48	6.13	6.25	5.49	5.54	6.48	6.61
C12	2.76	2.82	3.31	3.38	3.18	3.24	2.83	2.86	6.23	6.36
C13	1.66	1.69	2.09	2.13	2.13	2.18	1.83	1.85	2.73	2.78
C14	2.08	2.12	2.15	2.19	2.32	2.36	2.57	2.59	2.75	2.81
C15	2.19	2.24	2.31	2.36	2.47	2.52	2.71	2.74	2.68	2.74
C16	2.16	2.20	2.52	2.57	2.63	2.68	2.78	2.81	2.78	2.83
C17	2.22	2.26	2.49	2.54	2.61	2.66	2.76	2.79	2.81	2.87
C18	2.48	2.53	2.43	2.48	2.54	2.59	2.70	2.72	2.58	2.63
C20	5.02	5.13	5.38	5.49	5.46	5.57	5.76	5.81	5.28	5.38
C24	7.93	8.09	8.69	8.87	8.70	8.88	9.88	9.98	8.58	8.75
C28	6.43	6.56	7.16	7.30	7.03	7.17	7.91	7.99	6.65	6.79
C32	5.04	5.14	5.67	5.78	5.44	5.55	6.28	6.34	5.16	5.27
C36	3.76	3.84	4.26	4.35	4.00	4.08	4.74	4.78	3.84	3.91
C40	2.82	2.87	3.22	3.29	2.95	3.01	3.57	3.61	2.87	2.93
C50	4.50	4.60	5.44	5.55	4.74	4.84	5.79	5.85	4.70	4.79
C52	0.73	0.74	0.42	0.43	0.68	0.70	0.80	0.81	0.67	0.69
C60	-	-	-	-	0.95	0.97	1.19	1.21	2.11	2.16

*Tab. 2. Component composition of oil. **Content, mass. %. *Component weight, g*

Well	Water cut, %	Dynamic viscosity, mPa·s
1	13.0	11.9
2	46.0	29.8
3	31.0	14.9
4	2.8	10.2
5	3.7	6.5

Tab. 3. Values of dynamic viscosity of well production

The models were calibrated using the bottomhole pressure, since telemetry systems were installed on these wells. The excess of the actual dynamic level from the calculated one in the wells is most likely due to inaccuracy in recalculating the pressure at the ESP inlet to the fluid level in the annulus (incorrect calculation of the fluid density in the annulus). In order to improve the accuracy and reliability of determining the bottomhole pressure and the dynamic level, it is recommended to use modern methods for calculating the pressure distribution in the well taking into account the changes in the parameters of the gas-liquid mixture in the annulus and the wellbore profile (Chernykh et al., 2017; Menad Nait Amar et al., 2018).

Modeling of paraffin deposition in wells

Modeling of wax deposition within the framework of hydrodynamic calculations was carried out using the models described earlier and presented in Figure 1. Modeling of wax deposition was carried out for five days period. The probable presence of deposits in the pipe at the time of the start of the calculation was not taken into account. The hydraulic calculation determined the place of deposition, the maximum thickness of the

Well	Formation temperature, ^{0}C	Formation pressure, MPa	Productivity index, m^3/(day·MPa)	Gas factor, m^3/t
1	30.8	14.82	10.304	101.6
2	30.8	14.71	11.865	101.6
3	31.8	16.89	21.393	154.2
4	30.8	15.26	9.538	101.6
5	31.8	16.65	12.363	154.2

Tab. 4. Characteristics of wells and reservoirs

Well	Type of pumping equipment	Landed depth, m	Liquid rate, m^3/day	Water cut, %	Wellhead pressure, MPa	Annular pressure, MPa
1	ESP-60-2000	1812	57.4	13.0	1.90	1.98
2	ESP-60-1750	2029	59.9	46.0	2.80	0.52
3	ESP-125-2000	1949	103.3	31.0	3.00	2.02
4	ESP-35-2000	1750	29.6	3.5	1.80	1.95
5	ESP-35-2000	1894	51.2	3.7	2.00	1.83

Tab. 5. Initial data for hydraulic calculation

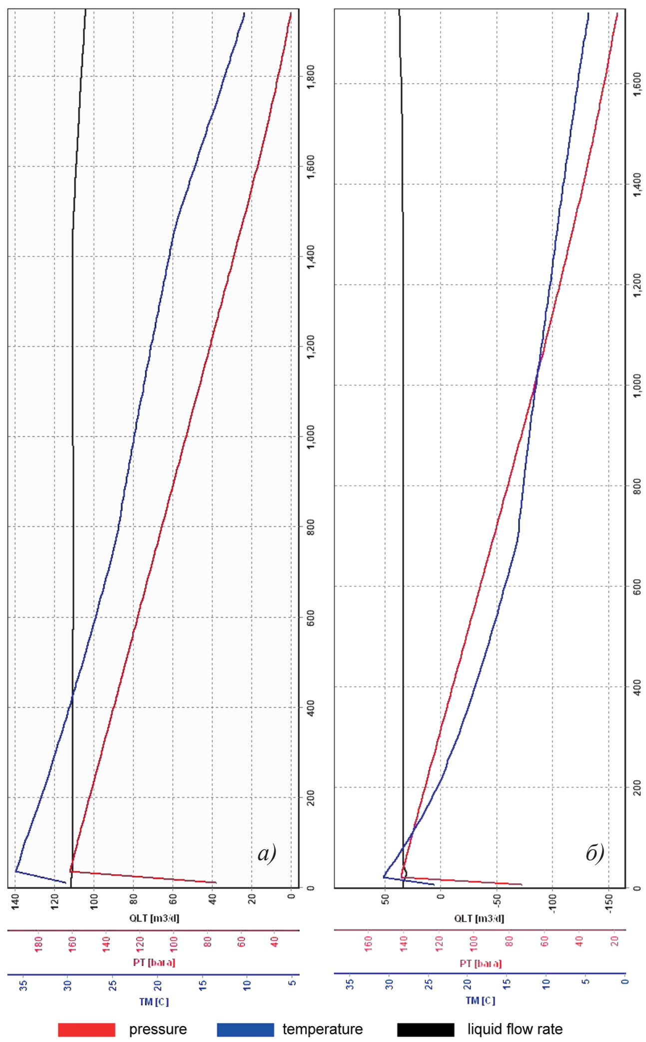

Fig. 1. Distribution of fluid flow rate, pressure and temperature along the length of the tubing (wellhead at the top of the figure): a) well 3; b) well 4

paraffin layer and the mass of deposited on the wall and suspended paraffin in the tubing and in the production casing. The results of modeling paraffin deposition within the framework of hydrodynamic calculation in wells (the results for wells 3 and 4 are presented) are presented in Figure 2 (each of the figures shows the distribution of the wax layer along the length of the tubing) and in Table 7.

When analyzing the data presented in Table 7, a high formation intensity of wax deposits in the well tubing was established. The depth value of the beginning of paraffin deposition varies in the range from 378 to 1112 m. In well No. 2, the formation of ARPD on the surface of the production casing is also recorded.

The base intercleaning period (ICP), which corresponds to the accumulation time of the wax layer with an average design rate, starting from the moment when the pipe surface is "clean" until the moment when 20% of the tubing section is waxed, averages 35 days.

Selection of technologies to prevent wax deposition in the analyzed wells

When analyzing measures to combat ARPD, the following methods were considered that are currently used in the considered field:

1. Mechanical – dewaxing plants;
2. Thermal – flushing with hot oil (HOF) and water with surfactants (HWF);
3. Chemical – flushing with a hydrocarbon solvent (HCF), inhibitor protection using the reagent supply units (RSU).

The effectiveness of the MDU, HOF, HWF and HCF methods is determined by the ratio of the mass of the removed paraffin from the tubing walls to the initial mass of paraffin. Based on the operating experience of wells equipped with MDU and the results of laboratory tests of hydrocarbon solvents, the following method efficiency was adopted in the calculations: MDU – 90%, HOF, HWF – 75%, HCF – 90%. The effectiveness of the inhibitor injection method, determined in laboratory conditions, is expressed in a decrease in the rate of wax deposition on the pipe surface, which for calculations was taken in accordance with the effectiveness of the selected inhibitor. Inhibitors, for wells on which no studies were carried out, were taken from similar wells.

The calculated ICP for the MDU, HOF, HWF and HCF methods was determined taking into account the removal efficiency and the rate of wax accumulation from the size of the remaining layer (after removal) to the moment the tubing section was blocked by 20%.

The diameter of the surface to be cleaned by means of MDU is 56 mm for tubing with a diameter of 73 mm, that is, the effect of the use of a scraper occurs when the thickness of deposits on the wall reaches more than 3 mm. Up to this point, ARPDs accumulate unhindered. The ICP for MDU is the time after which it is necessary to carry out flushing to remove deposits, with the current number of scraper runs, determined

Well	Bottom hole pressure calculated , MPa	Bottom hole pressure actual, MPa	Dynamic level calculated, m	Dynamic level actual , m	Deviation, %
1	8.53	7.66	1252	1146	9.25
2	8.79	8.22	1065	1182	-9.90
3	10.75	9.48	1175	1018	15.42
4	11.02	8.81	1046	998	4.81
5	13.68	12.63	477	434	9.91

Tab. 6. Summary data on the results of hydraulic calculation of wells

Well	Tubing						Basic ICP (waxing 20% of tubing section), days (calculated parameter)
	Maximum thickness of the paraffin layer, microns	Depth of maximum layer thickness, m	The mass of the settled paraffin, kg	Weight of paraffin suspended in oil, kg	The volume of the settled paraffin, m^3	Depth of the beginning of paraffin deposition, m	
1	1142.5	10.0	13.17	1.03	0.079	560	27
2	1269.7	wellhead	7.16	0.02	0.042	690	24
3	645.3	6.0	3.88	0.30	0.023	378	48
4	666.2	755.5	15.36	10.01	0.088	1112	47
5	763.1	wellhead	9.12	1.15	0.055	526	41

Tab. 7. Summary data based on the results of modeling wax deposits in wells

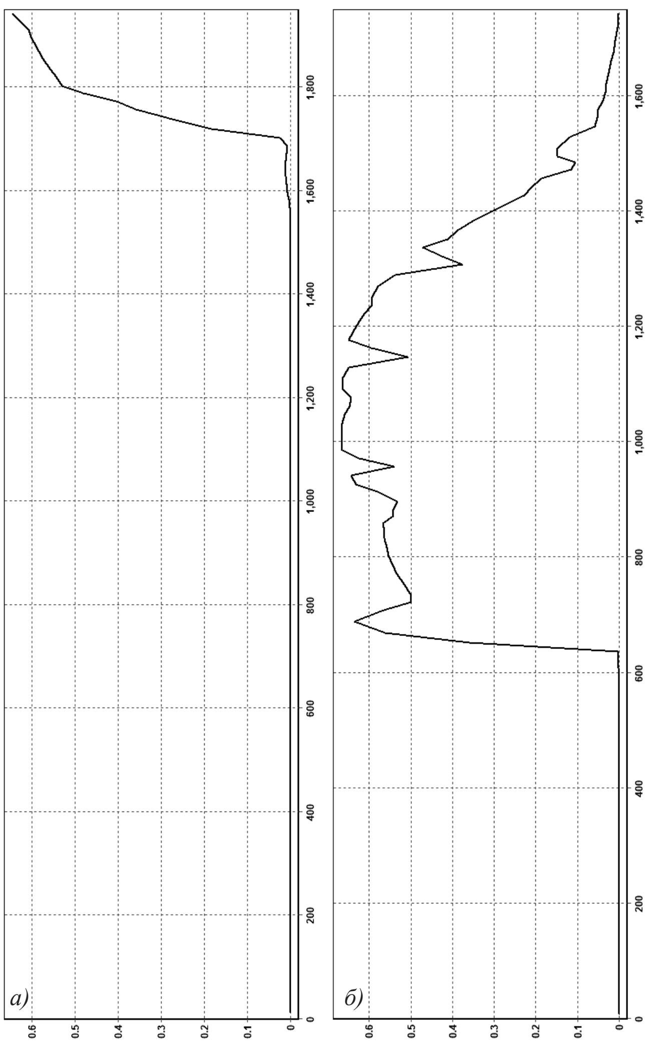

Fig. 2. Modeling of paraffin deposits (wellhead on the top of the figure): a) well 3; b) well 4

practically. The calculated ICP for the RSU method was determined taking into account the decrease in the wax deposition rate by an amount equivalent to the efficiency of the method until the moment of waxing of 20% of the tubing section (Table 8).

In wells 2, 3 and 5, the formation of wax in the annulus was found. At the moment, the main methods of control are hot flushing, HCF and the introduction of injection cable lines. These methods lead to significant costs and oil shortages. For these wells, it is recommended to increase the annular pressure to squeeze down the dynamic level below the depth of the beginning of wax deposition. For each of these wells, hydrodynamic modeling was carried out to select the optimal annular pressure to prevent the formation of ARPD (Table 9).

As a result of the change in the annular pressure, a decrease in foaming was established and the dynamic level stabilized at a constant value, while ARPD was not formed in the annulus.

Thus, based on the results of the presented calculations, recommendations were formed on the effective selection of technologies and technical means to prevent the formation of ARPD in production wells.

Well No. 1: Run the scraper 4 times a day; carry out preventive flushing with hot oil with ICP of 152 days.

Well No. 2: Increase the annular pressure up to 2 MPa to prevent the formation of ARPD in the annulus; run the scraper 2 times a day; carry out preventive flushing with hot oil with ICP of 135 days.

Well No. 3: Increase the annular pressure up to 3 MPa to prevent the formation of ARPD in the annulus; run the scraper 4 times a day; carry out preventive flushing with hot oil with ICP of 271 days.

Well No. 4: Run the scraper once a day at a depth of at least 1200 m; conduct preventive flushing with solvents in circulation or with pumping 1200 m with ICP of 265 days, since ARPD deposits in the tubing were recorded at a depth of more than 1100 m.

Well No. 5: Increase the annular pressure to 5.5 MPa to prevent the formation of ARPD in the annulus; run the scraper 4 times a day; carry out preventive flushing with hot oil with ICP of 231 days.

It is considered the most effective method of flushing with the help of HCF to remove ARPD deposits and achieve the calculated ICP, but their cost is much higher than flushing with hot oil or water (Table 10). Therefore, it is necessary to approach in detail the choice of wells where it is necessary to use HCF, and on which HOF/HWF. From the recommendations presented, it is clear that only in well 4, flushing should be carried out with the help of HCF, this is due to the depth of the beginning of paraffin deposition (more than 1100 m).

Well	Rate of wax deposition on the pipe wall, mm/month	Rate of wax deposition on the production casing wall, mm/month	Rate of wax deposition on the pipe wall, kg/day	Calculated ICP (20% of paraffin deposition), day			
				Standart	MDU (Э=90%)	HOF, HWF (Э=75%)	HCF (Э=90%)
1	6.86	-	2.63	27	152	20	24
2	7.62	0.78	1.43	24	135	18	22
3	3.87	1.59	0.78	48	271	36	43
4	4.0	-	3.07	47	265	35	42
5	4.58	1.59	1.82	41	231	31	37

Tab. 8. Summary data on the results of determining the inter-cleaning period of wells

Well	Current annular pressure, MPa	Recommended annular pressure, MPa	Calculated dynamic level, m
2	0.52	2.0	1269.0
3	2.02	3.0	950.0
5	1.83	5.5	700.0

*Tab. 9. Results of calculations to determine the optimal annular pressure. *Cost of flushing with hot oil / cost of flushing with oil and gas*

Well	Number of flushing	Calculated ICP, day	Total costs, thous.rub.
1	6	152	91800/201519.5*
2	7	135	107100/140619.6
3	4	271	61200/115738
4	4	265	301257.2
5	4	231	61200/332693.9

Tab. 10. Costs for well flushing operations

Conclusion

In this work, an urgent problem is considered – the selection of effective and economically viable methods for combating wax deposits on downhole pumping equipment. To solve this problem, computational hydraulic models were created, hydrodynamic modeling and modeling of paraffin deposits during lifting of fluid in a well were carried out using the example of five wells of one of the oil fields of the Perm Territory. Based on the calculations, recommendations were given on the choice of the method for removing and preventing ARPD for the analyzed wells. The proposed measures have been implemented at the wells and to date have led to a reduction in the costs of measures and significantly reduced oil shortages. At three wells, the change in annular pressure led to a decrease in foam formation and stabilization of the dynamic level, while the main problem was solved – ARPDs are not formed in the annulus.

The proposed approach to the selection of measures for the prevention and removal of ARPD seems appropriate to replicate to other producing wells of oil fields in the Perm Territory and Russia.

References

Akberova A.F. (2019). Selection of wells for the application of ARPD (asphaltene-resin-paraffin deposits) inhibitor. *SOCAR Proceedings*, 3, pp. 34–41. (In Russ.) https://doi.org/10.5510/OGP20190300396

Ali Piroozian, Mahmoud Hemmati, Mehdi Safari, Ali Rahimi, Omeid Rahmani, Shahram M. Aminpour, Amin Beiranvand Pour (2021). A mechanistic understanding of the water-in-heavy oil emulsion viscosity variation: effect of asphaltene and wax migration. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 608, 125604. https://doi.org/10.1016/j.colsurfa.2020.125604

Amin Tirjoo, Behrouz Bayati, Hossein Rezaei, Mahmoud Rahmati (2019). Molecular dynamics simulations of asphaltene aggregation under different conditions. *Journal of Petroleum Science and Engineering*, 177, pp. 392–402. https://doi.org/10.1016/j.petrol.2019.02.041

Antipenko V.R., Grinko A.A., Golovko A.K., Melenevsky V.N. (2018). Comparative characteristics of insoluble products obtained by autoclave thermolysis of resins and asphsltenes from the Usinskaya oil. *Izvestiya Tomskogo politekhnicheskogo universiteta. Inzhiniring georesursov = Bulletin of the Tomsk Polytechnic University. Engineering of georesources*, 329(6), pp. 106–117. (In Russ.)

Ce Zheng, Manuel Brunner, Hua Li, Dongke Zhang, Rob Atkin (2019). Dissolution and suspension of asphaltenes with ionic liquids. *Fuel*, 238, pp. 129–138. https://doi.org/10.1016/j.fuel.2018.10.070

Chernykh I.A., Galkin V.I., Ponomareva I.N. (2017). Comparative analysis of the methods for defining bottom hole pressure at well operation of Shershnevsky field. *Izvestiya Tomskogo politekhnicheskogo universiteta. Inzhiniring georesursov = Bulletin of the Tomsk Polytechnic University. Engineering of georesources*, 328(8), pp. 41–47. (In Russ.)

Cheshkova T.V., Sergun V.P., Kovalenko E.Yu., Sagachenko T.A., Min R.S. (2018). Structure of asphaltenes occurring in oils of different chemical nature. *Izvestiya Tomskogo politekhnicheskogo universiteta. Inzhiniring georesursov = Bulletin of the Tomsk Polytechnic University. Engineering of georesources*, 329(9), pp. 61–71. (In Russ.)

Daiwei Lui, Fei Yang, Guangyu Sun, Jia You, Kaixiang Cui (2019). Synergetic effect of resins and asphaltenes on water/oil interfacial properties and emulsion stability. *Fuel*, 252, pp. 581–588. https://doi.org/10.1016/j.fuel.2019.04.159

Denisson Santos, Monique Amaral, Elvio B.M. Filho, Raul S. Dourado (2019). Revisiting the methology for asphaltene precipitation. *Journal of Petroleum Science and Engineering*, 178, pp. 778–786. https://doi.org/10.1016/j.petrol.2019.03.074

Fahad I. Syed, Mohamed Boukhatem, Ahmed A. Al Kiyoumi (2019). Lean HC gas injection pilots analysis and IPR back calculation to examine the impact of asphaltene deposition on flow performance. *Petroleum Research*, 4(1), pp. 84–95. https://doi.org/10.1016/j.ptlrs.2018.11.006

Fahad I. Syed, Shahin Neghabhan, Arsalan Zolfaghari, Amirmasoud K. Dahaghi (2020). Numerical Validation of Asphaltene Precipitation and Deposition during CO2 miscible flooding. *Petroleum Research*, 5(3), pp. 235–243. https://doi.org/10.1016/j.ptlrs.2020.04.002

Fatykhov L.M., Galkin S.V., Fatykhov M.A. (2018). Implementation of numerical modelling to assess efficiency electromagnetic technology of cleaning of wells from wax deposition. *Neftyanoe hozyajstvo = Oil industry*, 8, pp. 56–59. (In Russ.) https://doi.org/10.24887/0028-2448-2018-8-56-59

Griselda Garcia-Olvera, Teresa M. Reilly, Teresa E. Lehmann, Vladimir Alvarado (2016). Effects of asphaltenes and organic acids on crude oil-brine interfacial visco-elasticity and oil recovery in low-salinity waterflooding. Fuel, 185, pp. 151–163. https://doi.org/10.1016/j.fuel.2016.07.104

Han Zhao, Wanli Kang, Hongbin Yang, Zitong Huang, Bobo Zhou, Bauyrzhan Sarsenbekuly (2021). Emulsification and stabilization mechanism of crude oil emulsion by surfactant synergistic amphiphilic polymer system. *Colloids and Surfaces A: Physicochemical and Engineering Aspects,* 609, 125726. https://doi.org/10.1016/j.colsurfa.2020.125726

Ilyushin P.Yu., Lekomtsev A.V., Ladeishchikova T.S., Rakhimzyanov R.M. (2018). The efficiency assessment of the «cold flow» method against the deposition of asphaltenes, resins and paraffins. *Vestnik PNIPU. Geologiya. Neftegazovoe i gornoe delo = Bulletin of PNIPU. Geology. Oil and gas and mining*, 18(1), pp. 53–62. (In Russ.) https://doi.org/10.15593/2224-9923/2018.3.5

Jaber Azizi, Seyed Reza Shadizadeh, Abbas Khaksar Manshad, Amir H. Mohammadi (2019). A dynamic method for experimental assessment of scale inhibitor efficiency in oil recovery process by water flooding. *Petroleum*, 5(3), pp. 303–314. https://doi.org/10.1016/j.petlm.2018.07.004

Matiev K.I., Agazade A.D., Keldibaeva S.S. (2016). Removal of asphalt-resin-paraffin deposits of various deposits. *SOCAR Proceedings*, 4, pp. 64–68. (In Russ.) https://doi.org/10.5510/OGP20160400299

Menad Nait Amar, Nourddine Zeraibi, Kheireddine Redouane (2018). Bottom hole pressure estimation using hybridization neural networks and grey wolves optimization. *Petroleum*, 4(4), pp. 419–429. https://doi.org/10.1016/j.petlm.2018.03.013

Mohamed Mehana, Jocin Abraham, Mashhad Fahes (2019). The impact of asphaltene deposition on fluid flow in sandstone. *Journal of Petroleum Science and Engineering*, 174, pp. 676–681. https://doi.org/10.1016/j.petrol.2018.11.056

Sara M. Hashmi, Abbas Firoozabadi (2013). Self-assembly of resins and asphaltenes facilitates asphaltene dissolution by an organic acid. *Journal of Colloid and Interface Science*, 394, pp. 115–123. https://doi.org/10.1016/j.jcis.2012.11.069

Sousaa A.M., Matos H.A., Guerreiro L. (2020). Wax deposition mechanisms and the effect of emulsions and carbon dioxide injection on wax deposition. Critical review. *Petroleum*, 6(3), pp. 215–225. https://doi.org/10.1016/j.petlm.2019.09.004

Suzev A.V., Lekomtsev A.V., Martyushev D.A. (2018). Complex method of selecting reagents to delete asphaltenosmolaparinine deposits in mechanized oil-producing wells. *Izvestiya Tomskogo politekhnicheskogo universiteta. Inzhiniring georesursov = Bulletin of the Tomsk Polytechnic University. Engineering of georesources*, 329(1), pp. 15–24. (In Russ.)

Virstyuk A.Yu., Mishina V.S. (2020). Application of regression analysis to evaluate the efficiency of oil well operating with the paraffin oil. *Izvestiya Tomskogo politekhnicheskogo universiteta. Inzhiniring georesursov = Bulletin of the Tomsk Polytechnic University. Engineering of georesources*, 331(1), pp. 117–124. (In Russ.)

Vyatkin K.A., Martyushev D.A., Lekomtsev A.V. (2015). Technology of cleaning pump-compressor pipes from asphaltene-resin-paraffin deposits with the subsequent disposal. *Neftyanoe hozyajstvo = Oil industry*, 3, pp. 36–38. (In Russ.)

Zeeshan Rashid, Cecilia Devi Wilfred, Nirmala Gnanasundaram, Appusamy Arunagiri, Thanabalan Murugesan (2019). A comprehensive rewiew on the recent advances on the petroleum asphaltene aggregation. *Journal of Petroleum Science and Engineering*, 176, pp. 249–268. https://doi.org/10.1016/j.petrol.2019.01.004

Zlobin A.A. (2018). Effect of fractal dimension of asphaltene aggregates on macro properties of native oil. *Vestnik PNIPU. Geologiya. Neftegazovoe i gornoe delo = Bulletin of PNIPU. Geology. Oil and gas and mining*, 17(2), pp. 136–151. (In Russ.) https://doi.org/10.15593/2224-9923/2018.2.4

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Manuscript received 21 November 2019;
Accepted 17 September 2020; Published 11 December 2020