

4. Petrik, M., Szepesi, G. L. (2018). Shell Side CFD Analysis of a Model Shell-and-Tube Heat Exchanger. *Chemical engineering transactions*, 70, 313–318. doi: <http://doi.org/10.3303/CET1870053>
5. *Heat Transfer Optimization of Shell-and-Tube Heat Exchanger through CFD Studies* (2011). Goteborg: Chalmers University of Technology, 39.
6. Zenkevich, O. (1975). *The finite element method in technology*. Moscow: Mir Publishing House, 541.
7. Menter, F. R. (1997). Eddy Viscosity Transport Equations and Their Relation to the $k-\epsilon$ Model. *Journal of Fluids Engineering*, 119 (4), 876–884. doi: <http://doi.org/10.1115/1.2819511>
8. Menter, F. R. (1994). Two-equation eddy-viscosity turbulence models for engineering applications. *AIAA Journal*, 32 (8), 1598–1605. doi: <http://doi.org/10.2514/3.12149>
9. Belov, I. A. (2001). *Modeling turbulent flows*. Saint Petersburg: BSTU, 107.
10. Florea, O., Smigelsky, O.; Kagan, S. Z. (Ed.) (1971). *Calculations for processes and devices of chemical technology*. Moscow: Chemistry, 448.
11. Kern D. (1950). *Process Heat Transfer*. McGraw-Hill, 871.

Pyrohov Tymofii, Head of Department, Division of Strength Analysis of Elements of Nuclear Installations, State Enterprise «State Scientific Engineering Center of Control Systems and Emergency Response», Kyiv, Ukraine, e-mail: T.V.Pirogov@gmail.com, ORCID: <http://orcid.org/0000-0002-0877-1251>

Korolev Alexander, Doctor of Technical Sciences, Professor, Department of Nuclear Power Plants, Odessa National Polytechnic University, Odessa, Ukraine, e-mail: Korolyov118@gmail.com, ORCID: <http://orcid.org/0000-0002-7898-8659>

UDC 553.982.2

DOI: 10.15587/2706-5448.2020.217921

Liashenko A.

INVESTIGATION OF HYDROCARBON SOLVENTS FOR THE CONTROL OF PARAPHYN-HYDRATE DEPOSITS IN OIL WELLS

The object of research is hydrocarbon solvents for the elimination of paraffin-hydrate deposits. The chemical methods of control of paraffin-hydrate deposits, in particular, application of hydrocarbon solvents are considered in the article. Studies of the effect of various chemical reagents on the dissolution of hydrate formations using a laboratory installation at different thermo-baric regimes, closest to the real conditions of the pipe space of oil and gas wells: the temperature varied discretely from -10 to $+40$ °C and pressure from 0 to 10 MPa. To study the effect of hydrocarbon solvents on the process of removing hydrate formations, the most rational methods of regression analysis and mathematical planning of the experiment were used – simplex-grid planning. The G-criterion of plan optimality was used, which includes 22 experiments. The synthesis of the plan was implemented by numerical methods on a software-controlled device for information processing. The use of such methods makes it possible to reasonably organize experimental research, adjust the time, equipment, materials and perform the required number of experiments. The results of measurements are shown in the diagrams for each solvent separately. The obtained data allowed to a priori substantiate the choice of the optimal variant of application of chemical reagents for complete dissolution and removal of paraffin-hydrate formations from the surface of the internal well equipment. Analysis of the data shows that the solubility reagents butyl cellosolve and ethylacetat solvents, which can be recommended for wide application in the oil and gas industry, are characterized by the highest solubility and efficiency for removal of paraffin-hydrate deposits from the surface of well equipment. An important fact is that the consumption of the proposed solvents per one well operation is not more than 4 m^3 , which is 2–3 times less than in other known analogues. The use of new solvents also allows to increase the inter-cleaning period of the well more than 2–3 times, which reduces the cost of extracted products.

Keywords: paraffin-hydrate deposits, hydrocarbon solvent, internal well equipment, chemical reagent, well cleaning interval.

Received date: 06.08.2020

Accepted date: 22.09.2020

Published date: 31.12.2020

Copyright © 2020, Liashenko A.

This is an open access article under the CC BY license

<http://creativecommons.org/licenses/by/4.0>

1. Introduction

Resins, asphaltenes and paraffins are deposited on the surface of downhole equipment (casings and compressor pipes, pump housings, pump rods) along with hydrate formations.

It is necessary to use a multipurpose reagent for dissolving and removing all types of such deposits at the same time. Laboratory tests were performed to select such a chemical reagent.

The analysis of scientific literature sources showed there is a problem of precipitation of paraffin-hydrates in the process

of operation of most oil and gas condensate fields [1, 2]. These precipitations can be deposited in production wells and lead to emergencies due to the formation of paraffin plugs [3–5]. As known as the utilization of chemical methods, in particular, the use of solvents is the most economical and technological effective for the control paraffin-hydrate deposits. It is noted by the authors in [6–8], one of the main methods of protection of in-well equipment and oil field communications from hydrate formations and asphalt-resin-paraffin deposits is the use of hydrocarbon solvents. The entire operational fund of wells complicated by asphalt-resin-paraffin deposits and hydrate formations can be divided into four groups depending on the well cleaning interval (WCI) without the use of chemical reagents [9–11]:

- 1 – WCI up to 10 days;
- 2 – WCI from 10 to 20 days;
- 3 – WCI from 20 to 30 days;
- 4 – WCI more than 30 days.

For wells of 1 and 2 groups the use of chemical reagents for cleaning underground equipment should be combined in a certain sequence and dosing of inhibitors of paraffin-hydrate deposits. For the wells of 3 and 4 groups the most effective is the use of hydrocarbon solvents. Thus, *the object of research* is hydrocarbon solvents for the elimination of paraffin-hydrate deposits. *The aim of research* is to investigate the effect of hydrocarbon solvents on paraffinic hydrate deposits.

2. Research methods

Firstly, on a laboratory installation, the schematic diagram of which is shown in Fig. 1, studies of the effect of different types of chemicals on the dissolution of hydrate formations as the most insoluble for removal. The experiments were performed in the following thermobaric modes: the temperature varied discretely from –10 to +40 °C, the pressure from 0 to 10 MPa, which is most consistent with the real modes of the pipe space of oil and gas wells. The experiments were carried out as follows: if the temperature was constant, for example, 0 °C, the pressure changed discretely from 0 to 10 MPa and vice versa, at a constant (fixed) pressure, the temperature changed.

Samples of tubing 1.4 m long, 72 mm in diameter made of 36G2C steel and formation water-oil mixture were used as objects of research. Butyl cellosolve, ethyl acetate SNPH-7p and SNPH-7p-14, ethylbenzene and butylbenzene fractions were used as reagents. Chemical reagents were poured into the pressure chamber in the amount of 1, 2, 3, 4 and 5 liters, based on the calculation of 10–50 liters per 1 m³ of internal volume of the well.

To study the effect of hydrocarbon solvents on the process of removing hydrate formations from downhole equipment, quantitative description of this effect and significantly reduce the number of experiments, rationally apply the methods of regression analysis and mathematical planning of the experiment – simplex lattice planning. Since specific hydrocarbon solvents can't be sold throughout the study area, additional restrictions are imposed on them. As a result, the planning area becomes complex. In this area, it is advisable to use the G-criterion of plan optimality [12], which includes 22 experiments and minimizes the maximum value of the variance of the predicted values (Fig. 2). The application of the G-optimal plan ensures that there are no points in the planning area where the accuracy of the response sur-

face estimate is not too low. The synthesis of the plan was implemented by numerical methods.

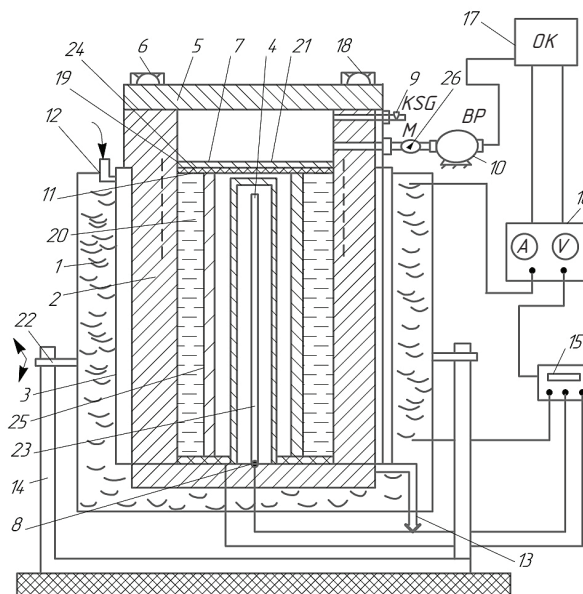


Fig. 1. Schematic diagram of the experimental installation:
1 – furnace; 2 – chamber of cylindrical shape; 3 – cooling jacket; 4 – tube; 5 – means of cover; 6 – squeeze bolts; 7 – insulation (textolite) gasket; 8, 15 – electronic potentiometers; 9 – nipple (KSG – nipple model); 10 – booster pump (BP); 11 – grooves; 12 – special device; 13 – crane; 14 – frame; 16 – autotransformer with an ammeter and a voltmeter; 17 – computational complex (OK); 18 – pulse tube; 19 – groove; 20 – objects of research (samples of tubing and formation water-oil-gas liquid); 21, 25 – upper and lower walls; 22 – pins; 23 – electric heater; 24 – inner lid; 26 – manometer (M)

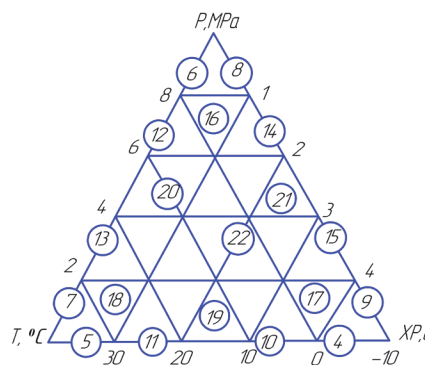


Fig. 2. The plan of the experiment on the triple diagram

In accordance with the requirements of the plan, hydrocarbon solvents (22 brands of each system) were selected. The content of each solvent varied from 0 to 100 %, while the total content of the three solvents remained unchanged at 100 %. The experiments resulted in the construction of fifth-order multiple regression equations (regression coefficients significant at the level of $\alpha \leq 0.05$), which were used to construct equal-level lines on triple diagrams. The adequacy of the obtained regression equations was checked using Fisher's F-test [13] at the 5 % level of significance. The value of the correlation coefficients $r = 0.97-0.99$, which indicates a good correspondence of the experimental data to the given regression equation and the possibility of using them as formal calculation models.

The duration of the experiments was 12 hours. At the end of each experiment, the contents of the pressure chamber

were poured into a container, and the sample tubing tube and the inner surface of the chamber were thoroughly cleaned of deposits, which were then weighed on electronic scales to the nearest 0.001 g.

3. Results of research and discussion

The measurement results are shown in Fig. 3–8.

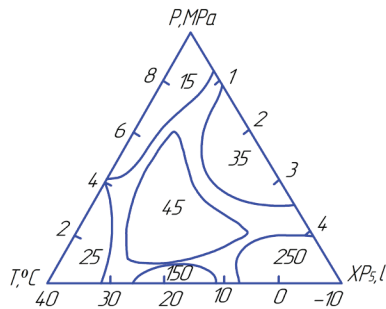


Fig. 3. The mutual influence of temperature, pressure and the amount of chemical reagent of the ethylbenzene fraction on the amount of hydrate formation (g)

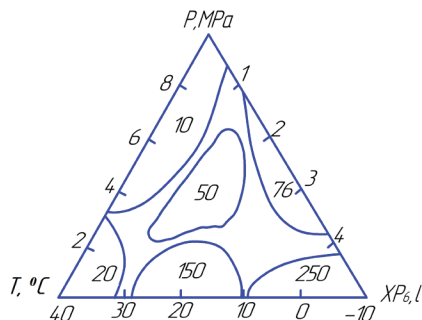


Fig. 4. The mutual influence of temperature, pressure and the amount of chemical reagent of butylbenzene fraction on the amount of hydrate formation (g)

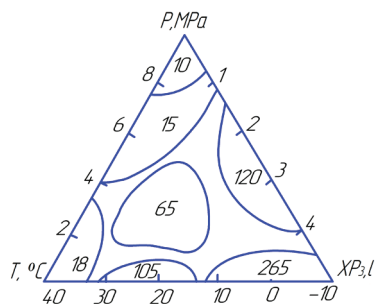


Fig. 5. The mutual influence of temperature, pressure and the amount of chemical reagent SNPH-7r on the amount of hydrate formation (g)

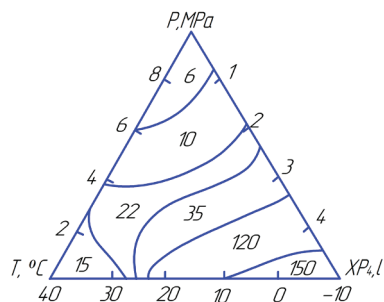


Fig. 6. The mutual influence of temperature, pressure and the amount of chemical reagent SNPH-7r-14 on the amount of hydrate formation (g)

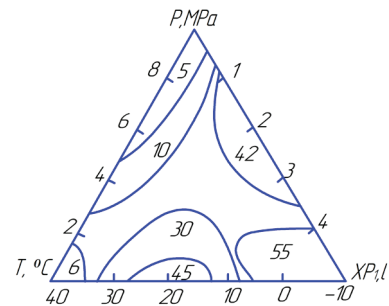


Fig. 7. The mutual influence of temperature, pressure and the amount of chemical reagent butyl cellosolve on the amount of hydrate formation (g)

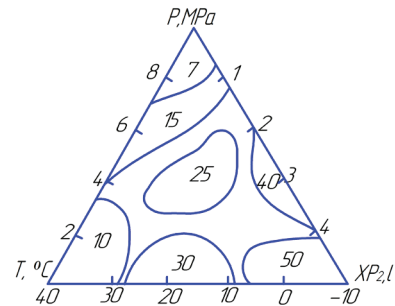


Fig. 8. The mutual influence of temperature, pressure and the amount of chemical reagent of ethyl acetate on the amount of hydrate formation (g)

Analysis of the obtained data shows that the best dissolving properties have butyl cellosolve and ethyl acetate in all studied thermobaric regimes. Their solubility reaches about 90–95 %. Composite hydrocarbon solvents SNPH-7r-14 and SNPH-7r showed a fairly high solubility (40–60 %).

Widely used chemicals in the fields – ethylbenzene and butylbenzene fractions – are characterized by very low solubility (on average 15–20 %) of hydrate formations, although, as is known from practice, they dissolve asphalt-resin-paraffin deposits quite well [14]. The obtained data allowed to a priori substantiate the choice of the optimal variant of application of chemical reagents for complete dissolution and removal of hydrate formations from the surface of internal well equipment. Butyl cellosolve and ethyl acetate are the most effective to inject into the well (inside the tubing and annulus). It should be noted that the calculated consumption of solvents is 2–4 l per 1 m³ of well volume, i. e. on average 2–4 m³ per well with a depth of 1.5–2.5 km.

4. Conclusions

Using an information-measuring system using the method of mathematical planning of experiments, the influence of chemical reagents on the dissolution of paraffinic deposits in a wide range of temperature and pressure changes was studied: the temperature varied discretely from –10 to +40 °C and pressure from 0 to 10 MPa. It was found that the greatest solubility and cleaning ability are characterized by hydrocarbon solvents – butyl cellosolve and ethyl acetate, which can be recommended for widespread use in the oil and gas industry. The use of new solvents allows to increase the inter-cleaning period of the well by more than 2–3 times, to increase its productivity by 5–10 times and to restore the initial properties by up to 90 %.

References

1. Akhfash, M., Aman, Z. M., Ahn, S. Y., Johns, M. L., May, E. F. (2016). Gas hydrate plug formation in partially-dispersed water-oil systems. *Chemical Engineering Science*, 140, 337–347. doi: <http://doi.org/10.1016/j.ces.2015.09.032>
2. Ivanova, I. K., Koryakina, V. V., Semenov, M. E. (2018). Investigation of the hydrate formation process in emulsions of asphaltene-resin-paraffin deposits by dsc method. *Fundamental Research*, 11, 143–149. doi: <http://doi.org/10.17513/fr.42313>
3. Davies, S. R., Boxall, J. A., Koh, C., Sloan, E. D., Hemmingsen, P. V., Kinnari, K. J., Xu, Z.-G. (2009). Predicting Hydrate-Plug Formation in a Subsea Tieback. *SPE Production & Operations*, 24 (4), 573–578. doi: <http://doi.org/10.2118/115763-pa>
4. Greaves, D., Boxall, J., Mulligan, J., Sloan, E. D., Koh, C. A. (2008). Hydrate formation from high water content-crude oil emulsions. *Chemical Engineering Science*, 63 (18), 4570–4579. doi: <http://doi.org/10.1016/j.ces.2008.06.025>
5. Turner, D. J., Miller, K. T., Dendy Sloan, E. (2009). Methane hydrate formation and an inward growing shell model in water-in-oil dispersions. *Chemical Engineering Science*, 64 (18), 3996–4004. doi: <http://doi.org/10.1016/j.ces.2009.05.051>
6. Tronov, V. P. (1970). *Mekhanizm obrazovaniia smoloparofinovykh otlozhenii i borba s nimi*. Moscow: Nedra, 200.
7. Khoroshilov, V. A., Semin, V. I. (1990). *Preduprezhdenie gidratoobrazovaniia pri dobyche nefi. Prirodnye i tekhnogemnye gazovye gidraty*. Moscow: Nedra, 220.
8. Maganov, R., Vakhitov, G., Batalin, O. (2000). Optimalnaia tekhnologiia borby s gidratoparafinovymi otlozheniiami. *Neft Rossii*, 3, 96–99.
9. Viatchinin, M. G., Pravednikov, N. K., Batalin, O. Iu. et. al. (1998). Usloviia i zony gidratoobrazovaniia v zatrubnom prostranstve neftianoi skvazhiny. *Neftianoe khoziaistvo*, 2, 56–57.
10. Viatchinin, M. G., Pravednikov, N. K., Batalin, O. Iu. et. al. (2001). Zakonomernosti gidratoobrazovaniia v zatrubnom prostranstve neftianoi skvazhiny. *Neftianoe khoziaistvo*, 4, 54–57.
11. Viatchinin, M. G., Batalin, O. Iu., Schepkina, N. E. (2000). Opredelenie rezhimov i zon gidratoobrazovaniia v neftianykh skvazhinakh. *Neftianoe khoziaistvo*, 7, 38–44.
12. Kasatkin, O. G. (1974). K voprosu postroeniia G-optimalnykh planov na simplekse. *Primenenie matematicheskikh metodov dlia issledovaniia mnogokomponentnykh sistem*. Moscow, 64–69.
13. Zedginidze, I. G. (1976). *Planirovanie eksperimenta*. Moscow: Nauka, 390.
14. Svetlitskii, V. M., Demchenko, P. N., Zaritskii, B. V. (2002). *Problemy uvelicheniia proizvoditelnosti skvazhin*. Kyiv: Vid. Paliivoda A. V., 228.

Liashenko Anna, Senior Lecturer, Department of Oil and Gas Engineering and Technology, National University «Yuri Kondratyuk Poltava Polytechnic», Poltava, Ukraine, ORCID: <http://orcid.org/0000-0001-6560-9931>, e-mail: anliashenko14@gmail.com