ANNOTATION

of Jatykov Temirlan's
PhD thesis on the speciality 6D070800 – "Oil and gas business"
on the topic

"Design of advanced and complex methodology for design, execution and control of hydraulic fracturing work"

Relevance of the work.

It is well known that hydraulic fracturing, in particular propped fracturing, is one of the most effective methods of production stimulation. This type of stimulation is highly sophisticated technology that involves many stages, equipments and materials. Thus, there are many important different factors affecting the technology of hydraulic fracturing, for example, the choice of equipment, bottom-hole assembly systems, logistics and management, integration of hydraulic fracturing into the reservoir simulation model, etc. The main factors affecting the final efficiency of the designed hydraulic fracturing work are expressed in the form of an increase in production rate, and detailed in the following stages

- Creation of geological and geomechanical model in the well section for modelling the optimal fracture geometry;
- Materials selection for hydraulic fracturing under the given formations and wells conditions, namely hydraulic fracturing fluids and proppants;
- Pressures analysis during diagnostic injection to calibrate the geological and geomechanical model, hydraulic fracture geometry model, injection plan, volumes of fluids and proppants;
- Construction of a proppant injection schedule for various reservoir conditions and a given hydraulic fracture geometry
- Forecasting the potential increase in production rate depending on the fracture model and hydraulic fracturing injection parameters.

To date, the scientific and engineering communities have carried out a lot of research related to the above stages. Million tons of proppant and fluid have been successfully injected worldwide, and a large number of diagnostic, modelling, planning and fracturing techniques have been developed. Despite the large amount of information obtained as a result of such volume of works, there are still a large number of issues that create specific constraints. In particular, it is necessary to provide solutions to the following highlighted problems as identified above:

- a geomechanical model creation requires the use of a large amount of data, namely, special core analysis data to determine the rocks mechanical properties, creation of regression equations to derive continuous data of geomechanical properties along the wellbore, all of that requires significant resources, which is not always available, including the frequent absence of core samples for a given well; The solution to this problem can be the creation of an alternative methodology for building

a one-dimensional geological-geomechanical model based on the existing lithological column calibrated by one diagnostic injection;

- during selection of a proper hydraulic fracturing fluid, the difficulty often lies in the optimal selection of the components composition, appropriate concentrations, laboratory research methods depending on reservoir conditions, hydraulic fracturing technology, and other factors; data systematization, components classification, identification of conditions and criteria, selection of system-based laboratory analysis may simplify the selection of hydraulic fracturing fluids;

- there is a significant problem during proppant selection associated with the proppant flowback after hydraulic fracturing, which leads to problems during well life; as a solution, a matrix and an algorithm are proposed to select one or another material to fill the fracture;

- there are many uncertainties in the interpretation of the pressure drop behavior after the end of injection in the analysis of diagnostic fracture injection tests, in particular, the G-function used in the analysis is not analyzed with reference to lithology; the use could possibly open the way to refine the lithology stratification;

- currently available methodology of injection schedule is not suitable for low-permeability carbonate reservoirs under abnormally high formation pressures; the solution can be the analysis of similar works and the identification of injection parameters that contribute to the successful hydraulic fracturing;

- the existing methods for predicting the potential increase in production after hydraulic fracturing have limitations due to many assumptions, limited lithology, the accuracy of the methods is relative, a large amount of input data is required; systematization by classifying methods would give a generalized forecasting methodology.

Therefore the creation of an integrated methodology for the design and implementation of proppant fracturing requires additional research through an integrated approach and optimization of the above factors that affect the overall fracturing technology and final production.

Aim of work: Creation of an integrated comprehensive methodology for the design and application of proppant hydraulic fracturing in oil and gas fields, taking into account the formation geology, fracturing fluid formula, injected proppant composition, test and diagnostic injection, as well as the method of injection of the main proppant mass to achieve an increase in well productivity.

The following tasks were identified to achieve this aim:

- Creating methodology for building a one-dimensional geological-geomechanical model along the wellbore based on the use of well log data in conjunction with the analysis of mini-frac data;

- Review of modern chemical reagents for hydraulic fracturing fluids followed by laboratory experiments to select hydraulic fracturing fluid, and to obtain concomitant recommendation standards;

- Constructing the matrix and the corresponding decision-making algorithm to choose a particular method against proppant flowback based on the systematization of technologies of filling the fracture with proppant, materials used during injection, injection equipment;

- Developing a method for testing and studying the structural properties of proppant packs by scratching samples of sintered proppant;

- Studying and analyzing the mini-frac method, in particular, analysis and a new approach to the interpretation of the G-function to calibrate fracture geometry effectively, to clarify reservoir lithology, to determine fracture closure pressure and hydraulic fracturing fluid efficiency;

- Developing proppant injection method for reservoirs under abnormally high formation pressures and stresses;

- Research and review of methods for predicting an increase in production as a result of hydraulic fracturing and identification of the most significant factors.

Research methods.

A set of theoretical and experimental studies was used to solve the set tasks, namely, generalization and analysis of literature data, analysis of the experience of proppant fracturing carried out in the fields of western Kazakhstan, as well as drawing analogy, modelling, quantitative and qualitative observations, laboratory research, conducting a multifactor experiment, data analysis by tools of mathematical statistics. In addition, methods of algorithms design and block diagrams were used. Information processing equipments based on computer program products were used.

Scientific novelty of the work.

1. An integrated comprehensive methodology for the design and application of proppant hydraulic fracturing in oil and gas fields has been developed. It takes into account the formation geology, fracturing fluid formula, injected proppant composition, test and diagnostic injection, as well as the method of injection of the main proppant mass to achieve an increase in well productivity

2. A methodology for building a one-dimensional geological-geomechanical model along the wellbore based on the use of well log data in conjunction with the analysis of mini-frac data has been created. Creation of a one-dimensional geological, petrophysical and geomechanical model for hydraulic fracturing modelling can be carried out using a minimum amount of input data.

3. Hydraulic fracturing fluids were investigated depending on reservoir conditions and injection parameters:

- A set of laboratory methods for testing hydraulic fracturing fluids has been established: fluid thermo stability tests, shear testing, stability test to check changes in breaker concentrations, emulsion break test;

- The optimal procedure for the selection of hydraulic fracturing fluid has been selected, which satisfies three main tasks: to perform all the necessary technological functions, to preserve the initial reservoir characteristics, and to be easily and quickly cleaned up from the formation;

- The hydraulic fracturing fluid was investigated and the chemical composition was selected for a particular case of high-temperature deep-lying formations with temperature above 100 C.

4. The matrix and the corresponding decision-making algorithm to choose a particular method against proppant flowback was constructed:

- Fourteen currently relevant prevention methods against proppant flowback were systematized

- A table based on relatively accurate assumptions has been built as a matrix to propose initial decision-making approach which allows to conduct primary screening to select a method to combat proppant flowback for a given hydrocarbon field well in advance of the start of hydraulic fracturing

- An algorithm which allows working with the decision-making matrix was developed and tested. The proposed algorithm can be used as an engineering method.

5. A method for testing and studying the structural properties of proppant packs by scratching samples of sintered proppant was developed

- A sintering-device for testing proppant samples was developed

- The experiment results and the corresponding analysis of the rubberized proppant properties, namely, its strength characteristics are obtained

- It has been established that the sintering temperature is the most significant factor in the sintering of a proppant pack, the compression force of the proppant during sintering is the second most significant factor, and the sintering time is the least significant of the three considered factors affecting the sintering capacity of the proppant pack.

6. The mini-frac method was studied, in particular, given an analysis and a new approach to the interpretation of the pressure drop by its G-function after the end of injection

- The dependence of the G-function behavior from the lithological column till the main moment of fracture closure was revealed, and an appropriate explanation was given related to the fracture closure mechanism in multilayer formations

- An application example of the method was shown for multilayer formation of Jurassic terrigenous deposits

7. A proppant injection method for low-permeability carbonate rocks under abnormally high formation pressures and stresses was developed

- An optimal injection schedule for the main hydraulic fracturing was obtained to increase the injection efficiency, and to get the required fracture

- A preparation flow-chart of the hydraulic fracturing work before injection has been determined

8. Forecasting methods for production increase as a result of hydraulic fracturing have been investigated, and the most significant factors affecting potential growth have been identified, they are formation permeability, fracture conductivity, dimensionless fracture conductivity, fracture geometry, fracture-well connection.

The following scientific statements are to be defended.

1. Proprietary methodology for the design and application of proppant hydraulic fracturing in oil and gas fields. It takes into account the formation geology, fracturing fluid formula, injected proppant composition, test and diagnostic injection, as well as the method of injection of the main proppant mass to achieve an increase in well productivity.

2. The realization principle of one-dimensional geological-geomechanical model along the wellbore based on the use of well log data in conjunction with the analysis of mini-frac data.

3. Recommendations for the optimal selection of hydraulic fracturing fluid which satisfies three main tasks: to perform all the necessary technological functions, to preserve the initial reservoir characteristics, and to be easily and quickly cleaned up from the formation.

4. Recommendations for the selection of a method against proppant flowback based on the matrix and the corresponding decision-making algorithm.

5. Results of laboratory experiments for testing and studying the structural properties of proppant packs by scratching samples of sintered proppant, as well as a new device for carrying out the corresponding laboratory tests.

6. Analysis and a new approach to the interpretation of the pressure drop by its G-function after the end of injection.

7. Recommendations for planning proppant injection for low-permeability carbonate rocks under abnormally high formation pressures and stresses.

8. Application conditions of forecasting methods for production increase as a result of hydraulic fracturing, as well as the established dependences on the most significant factors.

Practical significance of the research results.

1. Design and calibration method of one-dimensional geological-geomechanical model helps to accelerate the fracture model calibration, to reduce the amount of data required for the model construction, prompt decision-making on further fracturing.

2. Recommendations for the optimal selection of hydraulic fracturing fluid can be used during the planning hydraulic fracturing operations at the stage of choosing the type of fluid and its parameters.

3. The resulting formulation of hydraulic fracturing fluid can be used as a base formulation for hydraulic fracturing operations.

4. The algorithm and matrix for selecting a particular method against proppant flowback is a preventive technique that can be used in the field at the stage of hydraulic fracturing design, thereby contributing to the optimization of hydraulic fracturing design when selecting a fracture filler.

5. Obtained method and the device for determining the structural properties of proppant by scratching samples can be used in field laboratories to control the quality of the used proppant, to determine its mechanical characteristics, and can be an

addition to the algorithm and matrix for choosing a method against proppant flowback.

6. A new approach to the interpretation of the G-function can improve understanding of the lithological structure, reduce the possibility of penetration into bottom waters, optimize fracture geometry.

7. Recommendations for planning proppant injection for low-permeability carbonate formations can be used in similar fields.

8. The proposed procedure for selecting forecasting methods of production increase as a result of hydraulic fracturing has practical significance in a preliminary assessment of the need for hydraulic fracturing and the corresponding parameters and geometry of the fracture.

Personal contribution of the author

- Modelling a one-dimensional geological-geomechanical model along the wellbore
- Theoretical and experimental studies on the optimal selection of hydraulic fracturing fluid
- Theoretical and experimental studies on the optimal selection of hydraulic fracture fillers to prevent proppant flowback
- Creation of a matrix and an algorithm for the primary selection of a method to combat proppant flowback
- Creation of a method and device for testing sintered proppant
- Development of a G-function analysis method and an explanation of the function behavior before the closure of the main fracture
- Research and development of recommendations for planning proppant injection and inflow stimulation for low-permeability carbonate rocks under abnormally high reservoir pressures and stresses
- Conditions generalization for the application of methods for predicting an increase in production as a result of hydraulic fracturing, as well as the establishment of dependencies from the most significant factors
- Literature review and data integration
- Formulation of research tasks
- Justification of methodological approaches
- Writing articles and participating in conferences

Approbation of the work

The main results of the study were reported and discussed at international conferences:

- International Scientific and Practical Conference “SPE Middle East Oil and Gas Show and Conference 2019» (Manama, Bahrain, 2019);

- XLII International Scientific and Practical Conference "Fundamental and Applied Scientific Research: Topical Issues, Achievements and Innovations" (Penza, 2021);

- XVI International Scientific and Practical Conference "Modern scientific research: topical issues, achievements and innovations" (Penza, 2021);

- L International Scientific and Practical Conference "Fundamental and Applied Scientific Research: Topical Issues, Achievements and Innovations" (Penza, 2021).

Publications

The main results of the study are presented in 10 publications, including 3 articles in publications from the list approved by the Committee for the Control of Education and Science of the Republic of Kazakhstan; 1 article in a scientific journal covered in the Scopus database, 1 – other scientific journal, 4 – in the proceedings of international conferences, 1 patent.

List of published works on the topic of the dissertation:

1. Jatykov T. E., Sagindykov B. Zh. Modern characteristics of hydraulic fracturing as an effective method to intensify production of hydrocarbons // «Oil and gas» journal. – Almaty, 2017. – №3(99). – P. 52-67. ISSN 1562-2932 (Print), ISSN 2708-0080 (Online).

2. Jatykov T. E., Sagindykov B. Zh., Bimuratkyzy K. Geological and geomechanical model for hydraulic fracturing design // «Oil and gas» journal. – Almaty, 2018. – № 6 (108). – P. 46-61. ISSN 1562-2932 (Print), ISSN 2708-0080 (Online).

3. Istayev A., Jatykov T., Kosset T. Hydraulic Fracturing in a Devonian Age Carbonate Reservoir: A Case Study // Paper presented at the SPE Middle East Oil and Gas Show and Conference. - Manama, Bahrain, 2019. Paper Number: SPE-194942-MS. https://doi.org/10.2118/194942-MS

4. Jatykov T.E., Sagindykov B. Zh., Bimuratkyzy K. Quick determination of the optimal fracture filler for hydraulic fracturing // «Oil and gas» journal. – Almaty, 2020. – №6 (120). – P. 74-92. ISSN 1562-2932 (Print), ISSN 2708-0080 (Online).

5. Jatykov T.E., Bimuratkyzy K. Complex interpretation and analysis of diagnostic hydraulic fracturing parameters applied for on Jurassic sandstones. // Proceedings of XVI int. scientific-practical conf. "Modern scientific research: topical issues, achievements and innovations." - Penza: "Science and Education". - 2021. – P. 49-55.

6. Jatykov T.E., Sagindykov B. Zh., Bimuratkyzy K. Hydraulic Fracturing Design Improvements by proppant flowback mitigation method application during Hydrocarbon Production // The Mining-Geology-Petroleum Engineering Bulletin. – 2021. - Vol.36, №1 – P. 99-109. https://doi.org/10.17794/rgn.2021.1.8.

7. Jatykov T.E., Bimuratkyzy K. The analysis of the results of dynamic experimental resin coated proppant properties measurements // Proceedings of XLII int. scientific-practical conf. «Fundamental and Applied Research: Current Issues, Achievements and Innovation». - Penza: "Science and Education". - 2021. – P. 50-54.

8. Patent #6224. A device for proppant curing and a method of its implementation. Publ. Republic of Kazakhstan, 02.03.2021.

9. Case Study: An Approach for Hydraulic Fracturing Minifrac G-Function Analysis in Relation to Facies Distribution in Multilayered Clastic Reservoirs. (SPE Production & Operations, 2021; Paper number: SPE-206751-PA. Published on 26.10.2021. https://doi.org/10.2118/206751-PA)

10. Jatykov T.E., Baimukhametov M.A., Sagindykov B. Zh. Valuable Stage During Hydraulic Fracturing Design Stage for Well Stimulation Purposes // Proceedings of L int. scientific-practical conf. «Fundamental and Applied Research: Current Issues, Achievements and Innovation». - Penza: "Science and Education". - 2021. – P. 46-52.

Structure and scope of the thesis

The dissertation work consists of an introduction, nomenclature and abbreviations, 8 sections, a conclusion, a list of references of 102 titles. The work is presented on 131 pages of typewritten text, includes 42 figures, 26 tables and 4 annexes.

Thesis summary.

The introduction substantiates the relevance of the dissertation work and presents its principal points.

The first section of the thesis shows an overview of existing approaches and techniques for the design and implementation of proppant hydraulic fracturing, as well as identifies and considers significant factors that cause problems in the design of hydraulic fracturing. The main considered points are the procedure for hydraulic fracturing design, approaches to modelling geological and geomechanical properties, systematizing the selection of hydraulic fracturing fluids, various methods of combating proppant flowback, methods for determining the structural properties of proppant, analyzes of mini-frac, design problems in carbonate formations, methods for predicting flow rates after hydraulic fracturing. As a result of this analysis, the goal and objectives of the dissertation are set.

In the second section, the issue of building a one-dimensional geological-geomechanical model for hydraulic fracturing design is considered. The method presented in this section is a systematic sequence that allows you to calculate and build a petrophysical, geological and geomechanical reservoir model for hydraulic fracturing modelling. The methodology uses a standard set of well logging data, as well as the results of mini-frac analysis, without requiring expensive amounts of data such as broadband acoustics or the presence of core studies.

The third section shows the results of experimental studies for the development of a method for the selection of hydraulic fracturing fluid. To solve this problem, a series of laboratory tests were selected and carried out to select one or another reagent for certain conditions, the necessary reagents were selected, the requirements for the hydraulic fracturing fluid were found and set. At the same time, to demonstrate the method a particular problem of fluid selection for certain

conditions was solved. The conditions are set according to the requirements of the injection mode, reservoir properties, as well as the optimal mode to put a well on stream.

The fourth section is devoted to the development of a matrix and an algorithm to combat proppant flowback. So one of the problems associated with proppant is its flowback during well life after the treatment, which results in many field problems described in this section. To solve this problem, preventive methods of combating proppant flowback were studied and systematized. Based on the systematization of fourteen methods and relatively accurate assumptions a table has been built as a matrix to propose initial decision-making approach as well as an algorithm that allows, with some accuracy and assumptions, to conduct primary screening to select a method to combat proppant flowback for a given hydrocarbon field well in advance of the start of hydraulic fracturing.

The fifth section is devoted to the development of an experimental method and device for determining the structural properties of proppants. It proposes an optimal method and device for studying proppants, provides an experimental procedure and the results of a demonstration test of a rubberized proppant. Several interesting patterns were identified, such as the significant influence of temperature, compression forces, and the time of sintering itself on the strength properties of the proppant pack. As a result of testing with this method and device, the informative value of the obtained data increases, the device itself is autonomous and multifactorial.

The sixth section covers the detailed interpretation of mini-frac data based on the G-function and the development of a new method for analyzing and interpreting this function. Interpretation using separation into layers and integrated G-function analysis from a geological point of view is shown. This made it possible to describe the structure of the lithological column, which helps in terms of the interpretation of geological and geomechanical parameters. In this case not only the G-function itself is analyzed, but also its derivative - enhanced G-function, lithological column, as well as known reservoir data from other techniques. This approach reduces the uncertainties in the construction of the fracture model.

In the seventh section, a methodology of injection schedule for low-permeability carbonate rocks under abnormally high reservoir pressures and stresses is presented. In this regards a hydraulic fracturing simulator was used based on real data from the work carried out on the carbonate formation. Based on this approach, an optimized injection schedule has been developed for the best placement of the proppant in such challenging geological conditions.

In the eighth section, research is carried out on methods for selecting forecasting methods of production increase as a result of hydraulic fracturing. The validation of the adaptive method for predicting the flow rate or the effect of hydraulic fracturing is shown, namely, using the example of specific conditions the limitation of the Economides method was shown without the use of adaptation. A

certain algorithm was given for the application of the new method, while the parameters were highlighted, the change of which within significant limits allows for reliable adaptation.

In the conclusion, the main results and conclusions of the dissertation work are presented.