Economic Evaluation of Applying the Technology of Water-Gas Stimulation of Formation to Enhance Oil Recovery

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Abstract. An algorithm is represented, which allows analyzing the feasibility of the technology of water-gas stimulation of formation to enhance oil recovery. The authors have logically identified three blocks of the data involved. The first block is the source data. The specifics are determined by a particular field and, accordingly, the water and gas consumption and the electricity tariff for the enterprise. Economic parameters are described as the equipment, project implementation, and depreciation costs. The accounted discount rate and property tax should be determined. The macro parameters that may affect the algorithm results have also been considered. I.e., the costs of the US Dollar and the Brent oil. Among the mining and geological parameters, the oil, water, and gas density have been considered, which determine, respectively, the consumption and the economic component of the project.

1. Introduction

Enhancing oil recovery and increasing the associated petroleum gas utilization rate have been among the most important problems of the oil and gas industry for many years. One of the veterans of scientific developments aimed at solving the most critical problem A.N. Drozdov in his works describes the technique and technology of water-gas stimulation of formation using pump-ejector systems [1, 2, 3, 4, 5]. Among others, the proposed technology addresses utilizing associated petroleum gas. The technology developed should significantly reduce capital investments in the effect's implementation. Various water-gas stimulation (WGS) technologies have been previously applied in more than a hundred fields of the world. Numerous studies have been performed, which have shown that in complicated mining and geological conditions, water-gas stimulation using APG is one of the most promising techniques for enhancing oil recovery [4-15, etc.].

The WGS technologies can be classified by the method of injecting water and gas, the ratio of displacing agents, the gas type and composition, the gas source, the water-gas mixture formation place, the displacement mode, the choice of process equipment to implement the technology, and the type of the object affected.

Alternating injection of water and gas into the formation known as the WAG (Water Alternating Gas Injection) technology is an earlier WGS technique. Here, water and gas are injected into the formation cyclically in rims. Another technique is the joint (simultaneous) injection of water and gas...
into the formation, known as SWAG (Simultaneous Water and Gas Injection) technology. Here, water and gas are injected into the formation as a water-gas mixture.

Almost all studies have noted a significant increase in oil recovery achieved by water-gas stimulation. However, it should be noted that in Russia, many studies on water-gas stimulation have further been stopped (at Samotlor, Novogodnee, Sovetskoye, and other fields) mainly due to technical and engineering problems, insufficient efficiency, and complications in the equipment operation.

Most of the fields where water-gas stimulation has been applied are in North and South America and Norway. Dry or rich hydrocarbon gases and carbon dioxide are usually injected. Most often, when using WGS, an increase in oil recovery by about 5% is reported, however, oil recovery enhanced by 20% has been noted in some fields. WGS has almost always been used as a tertiary oil recovery technique. Only later in the North Sea, the water-gas stimulation was performed from the very beginning of the development. It turned out to be highly effective there to enhance oil recovery in many fields.

2. Relevance
About 150 billion m³ of APG is annually burned in the world, while Russia is among the world leaders in APG flaring. In 2017, 12.9 billion m³ or 13.1% of the total APG production burned out in flares in Russia [7]. Along with Russia, Nigeria (≈ 14.5 billion m³ of APG per year), Iran (≈ 12 billion m³), Iraq (≈ 9 billion m³), the USA (≈ 7 billion m³), and Algeria (≈ 4.5 billion m³) use the APG flaring [3]. The reasons for the irrational use of APG are associated with many factors [7]: remoteness of fields from the petroleum gas collection and transportation infrastructure; limited access to the main gas pipeline system; lack of local consumers of the APG processing products, etc.

3. Research objective
When addressing the oil industry history, it is worth recalling that the hydrocarbon resource base has significantly deteriorated, and the share of hard-to-recover reserves increased. This refers to low-permeable reservoirs, high-viscosity oils, great depths of occurrence, and highly watered and depleted fields. Herewith, the economic evaluation of the project's efficiency is a relevant problem.

4. Theoretical
A technique for water-gas stimulation of formation has earlier been developed, which comprises the injection of water by a power pump into the ejector nozzle, pumping the gas out with an ejector, creating, dispersing, and increasing the pressure of the water-gas mixture by the ejector followed by the injection of the water-gas mixture into the injection wells of the water-gas stimulation site in the field, and a stimulation unit comprising a power pump, an ejector, a booster pump, and a line supplying water to the power pump, a water injection line, a gas pumping-out line, and a line to inject water-gas mixture into the injection wells. The known technique and the unit use only the first separation stage gas for water-gas stimulation and have a limited efficiency and application area due to the impossibility of pumping gas from the second and end separation stages and the water break tank of the preliminary water discharge unit.

To improve the efficiency and expand the application area by increasing the gas utilization rate, along with the first separation stage gas, the gas from the second and end separation stages and the water break tank should also be used for water-gas stimulation of formation.

In the research by A.N. Drozdov, the below technology advantages have been identified:
Table 1 The research by A.N. Drozdov

| ITEM NO. | PARAMETER                        | APPLICATION CRITERIA                                                                                                                                                                                                 |
|---------|----------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1       | Reservoir type                   | Terrigenous, porous carbonate and porous-fractured. Water-gas stimulation is effective compared to water-flooding in reservoirs of different wettability. However, according to the laboratory filtration studies, the efficiency in hydrophobic reservoirs is less than in hydrophilic rocks. |
| 2       | Occurrence depth                 | Not a limiting factor                                                                                                                                                                                                 |
| 3       | Presence of a gas cap            | Not a limiting factor                                                                                                                                                                                                 |
| 4       | Presence of oil-water zones      | The technology is applicable.                                                                                                                                                                                           |
| 5       | Net oil thickness                | Not a limiting factor                                                                                                                                                                                                  |
| 6       | Water-saturated thickness        | No limitation on the water-saturated thickness                                                                                                                                                                          |
| 7       | Shaliness                        | At high shaliness, the effect of ‘squeezing’ viscous oil out of the formation due to clay swelling is possible, which increases the displacement rate, as water-gas stimulation experiments on core material from the Russkoye field have shown. |
| 8       | Oil saturation                   | 5-90 %                                                                                                                                                                                                               |
| 9       | Porosity                         | The technology is applicable in reservoirs with different porosities.                                                                                                                                                   |
| 10      | Sandiness                        | The effect is negligible.                                                                                                                                                                                            |
| 11      | Permeability                     | Water-gas stimulation is most effective at a permeability over 20 μm².                                                                                                                                                 |
| 12      | Stratification factor            | Not a limiting factor                                                                                                                                                                                                  |
| 13      | Permeable heterogeneity          | Not a limiting factor                                                                                                                                                                                                  |
| 14      | Formation pressure               | 0.3-1.5 of the hydrostatic pressure                                                                                                                                                                                     |
| 15      | Formation temperature            | Not a limiting factor                                                                                                                                                                                                  |
| 16      | Formation oil viscosity          | Up to 217 mPa·s under the formation conditions, according to the experiments.                                                                                                                                           |
| 17      | Formation oil density            | Not a limiting factor                                                                                                                                                                                                  |
| 18      | Mineralization and ionic composition of | Not a limiting factor. The best results can be achieved with the use of water having an ionic composition and                                                                                                       |
|   |   |
|---|---|
| formation water | mineralization, which simultaneously suppress the coalescence of gas bubbles in the fluid and provide the greatest increase in oil recovery. Using surfactants contributes to getting stable water-gas mixtures, improving the performance of pumps and ejectors, and increasing oil recovery. |
| 19 | Paraffin content | Not a limiting factor |
| 20 | The content of asphaltene and resin substances | Not a limiting factor, but the adsorption of polar oil components in the formation may cause a change in the reservoir's hydrophobization degree. |
| 21 | Preferred development stage | Anyone. According to earlier studies, the greatest effect is observed when using water-gas stimulation from the beginning of development. However, even at the last stage, the water-gas stimulation effect is extremely significant. |
| 22 | Water cut | Not a limiting factor |
| 23 | Injection capacity | From 20 m³/day. |
| 24 | Oil and liquid production rates | Not a limiting factor |
| 25 | Development system, distance between wells | The development system is that used in the field (in most cases, in practice—with the maintenance of reservoir pressure). For water-gas stimulation, the existing water-flooding infrastructure (marginal, contour, etc.) and the oil and gas gathering system with the integrated pump-ejector system are used. The distance between wells can be different. |
| 26 | Applicability in multilayer fields drilled in a single pattern | Applicable but subject to additional research (developing systems for simultaneous-separate injection and measurement of the water-gas mixture flow rate in wells will be required). |
| 27 | Mixture pumping pressure | Up to 30 MPa. |
| 28 | The distance from the pump station to the injection wells | Can be different. Not a limiting factor. |
| 29 | Residual stock requirements | No specific requirements. But, naturally, the higher they are, the greater the technology effect. |
| 30 | Gas composition | Not critical for pumping a water-gas mixture by a pump-ejector system (it can be raw, wet gas, with hydrogen sulfide, or with a high nitrogen content; the gas preparation before injection is not required). |
Thus, the technology is applicable in hydrocarbon fields at various development stages, with characteristic problems of utilizing associated petroleum gas, and to enhance oil recovery. Companies developing fields characterized by the above parameters are Tatneft, Gazpromneft, Gazprom, Rosneft, Lukoil, etc. The Western ones are Statoil, BP, Shell, and ExxonMobil.

5. Practical significance & research results

1. It is advisable to economically evaluate the technology for the given parameters. Pump-ejector systems have the best technical and economic indicators and a lower price compared to their competitors.

The algorithm used for economic evaluation can be represented graphically as follows:
THE PROJECT FEASIBILITY

| Capital expenditures | kRUB |
|----------------------|------|
| Operating costs      | kRUB |
| Depreciation deductions | kRUB |
| Depreciation cost    | kRUB |
| Property tax         | kRUB |
| Income from the sale of additionally produced oil | kRUB |
| Income from the beneficial use of APG (petrochemicals)*** | kRUB |
| Gross profits        | kRUB |
| Net profit           | kRUB |
| Cash flow            | kRUB |
| Net cash flow        | kRUB |
| Discounted income    | kRUB |
| Accumulated discounted income | kRUB |
| Net discounted income | kRUB |

Figure 1 The algorithm used for economic evaluation

Thus, the algorithm allows estimating the accumulated discounted flow. At the given parameters, the project reaches payback by the third year of implementation. The results are shown in the figure below:

Accumulated discounted income

![Graph showing accumulated discounted income over time]

Figure 2 Accumulated discounted flow

Along with high economic efficiency, the technology of water-gas stimulation of formation to enhance oil recovery is characterized by excellent technical and engineering advantages. Injecting a
water-gas mixture in the fields with an optimal gas factor ensures high stimulation efficiency and the greatest increase in the oil recovery. Herewith, the water-gas stimulation does not require costly and labor-intensive high-pressure compressor stations. Reaching the pressure several times higher compared to ejector technologies is especially important. The water-gas stimulation can be implemented for both individual wells and clusters, including fields, while not being restricted on water consumption. One of the most critical technical and engineering advantages is achieving high efficiency by arranging equipment depending on the injection conditions to improve the performance.

6. Conclusions
The project aimed at solving the most critical problem of the oil industry—enhancing oil recovery and the use of associated petroleum gas—shows high efficiency in terms of both technical and process parameters and economic ones. Thus, the technology will significantly reduce capital and operating costs.

7. References
[1] Drozdov A N 2014 Problems of introducing water-gas impact on the reservoir and their solutions Oil industry 8 pp 100-104 https://oil-industry.net/Journal/archive_detail.php?ID=10023&art=225489 date accessed: 15.09.2020
[2] Drozdov N A 2011 Study of water-gas impact on the reservoir Oil industry 11 pp 80-83 https://elibRARY.ru/item.asp?id=17066079, date accessed: 09/15/2020
[3] Drozdov N A 2014 Pump and ejector systems for water-gas stimulation Lambert Academic Publishing 172 p http://spisok-literaturi.ru/books/nasosno-ezhektnorndie-sistemyi-dlya-vodogazovogo-vozdeystviya-na-plast_34843257.html, date accessed: 15.09
[4] Drozdov A N 2008 Technology and technique of oil production by submersible pumps in difficult conditions: Textbook for universities (M.: MAKS press) 312 p http://elib.gubkin.ru/en/content/13494, date accessed: 09/15/2020
[5] Drozdov N A 2014 Problems of introducing water-gas impact on the reservoir and their solutions Oil industry 8 pp 100-104 https://oil-industry.net/Journal/archive_detail.php?ID=10023&art=225489
[6] Fomkin A V, Zhdanov S A 2015 Improving the efficiency of oil recovery: the need and trends Drilling and oil 4 pp 3-5 https://burneft.ru/archive/issues/2015-04/14
[7] Drozdov N A 2011 Study of water-gas impact on the reservoir Oil industry 11 pp 80-83 https://elibRARY.ru/item.asp?id=17066079
[8] Drozdov N A 2014 Pump and ejector systems for water-gas stimulation Lambert Academic Publishing 172 p http://spisok-literaturi.ru/books/nasosno-ezhektnorndie-sistemyi-dlya-vodogazovogo-vozdeystviya-na-plast_34843257.html
[9] Berge L I, Stensen J A, Crapez B and Quale E A 2002 SWAG Injectivity Behavior Based on Siri Field Data SPE 75126 SPE DOE Improved Oil Recovery Symposium, Tulsa, Oklahoma, 13-17 April 2002 https://www.onepetro.org/conference-paper/SPE-75126-MS
[10] Righi E F and Pascual M 2007 Water-Alternating-Gas Pilot in the Largest Oil Field in Argentina: Chihuiedo de la Sierra Negra, Neuquen Basin SPE 108031 2007 SPE Latin America and Caribbean Petroleum Engineering Conference (Buenos Aires, Argentina) https://www.onepetro.org/conference-paper/SPE-108031-MS?sort=&start=0&q=SPE+108031&from_year=&peer_reviewed=&published_between=&from_year=&to_year=&rows=25#
[11] Quale E A, Crapez B, Stensen J A and Berge L I B 2000 SWAG Injection on the Siri Field - An Optimized Injection System for Less Cost SPE 65165 SPE European Petroleum Conference held in Paris (France) https://www.onepetro.org/conference-paper/SPE-65165-MS?sort=&start=0&q=SPE+65165&from_year=&peer_reviewed=&published_between=&from_year=&to_year=&rows=25#
[13] Stoilosits R F, Krist G J, Ma T D, Rugen J A, Kolpak M M and Payne R L 1995 Simultaneous Water and Gas Injection Pilot at the Kuparuk River Field Surface Line Impact SPE 30645 SPE Annual Technical Conference

[14] https://www.onepetro.org/conference-paper/SPE-30645-MS?sort=&start=0&q=SPE+30645&from_year=&peer_reviewed=&published_between=&fromSearchResults=true&to_year=&rows=25#

[15] Shi W, Corwith J, Bouchard A, Bone R and Reinbold E 2008 Kuparuk MWAG Project after 20 Years, SPE 113933, SPE DOE Improved Oil Recovery Symposium (Tulsa, Oklahoma) www.onepetro.org/conference-paper/SPE-113933-MS? sort = & start = 0 & q = SPE + 113933 & from_year = & peer_reviewed = & published_between = & fromSearchResults = true & to_year = & rows = 25 #

[16] Stepanova G S 2006 Gas and water-gas methods of impact on oil reservoirs (M.: Gazoil press) 200 p https://rusneb.ru/catalog/000200_000018_RU_NLR_bibl_1057034/

[17] RF patent No. 1735611 Method of operation of a liquid-gas ejector Auth. invented A N Drozdov, V I Igrevsky, P B Kuznetsov and others M cl F 04 F 5/04 app 03/21/1990 publ. 05/23/1992 19 https://www.fips.ru/iiss/document.xhtml?faces-redirect=true&id=71d2f5a89d3bc52939465fe9ae2a7b9e

[18] Kokorev V I 2009 Gas methods - a new technology for enhanced oil recovery Oilfield business 11 pp 24-27 https://elibrary.ru/item.asp?id=13077826

[19] Eder L V 2018 On the way to the passing On the bumps of PNG Drilling and oil 12 pp 4-14

[20] Shevchenko A K, Chizhov S I, Tarasov A V 2011 Preliminary results of injecting a finely dispersed water-gas mixture into the reservoir at a late stage of the development of the Kotovskoye field Oil industry 10 pp 100-102 https://elibrary.ru/item.asp?id=16972469

[21] Status and development prospects of the oilfield services market in Russia. Based on materials from Deloitte CIS Oil and Gas Vertical 22 http://www.ngv.ru/magazines/article/sostoyanie-i-perspektivy-razvitiya-nefteservisnogo-rynka-rossii-2014/

[22] Afeez O Gbadamosi, Joseph Kiwalabye, Radzuan Junin, Agi Augustine 2018 A review of gas enhanced oil recovery schemes used in the North Sea Journal of Petroleum Exploration and Production Technology 8 pp 1373–1387 https://doi.org/10.1007/s13202-018-0451-6

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