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REVIEW OF KEY PARAMETERS FOR PROPPANT HYDRAULIC RE-FRACTURING TECHNOLOGY

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This paper first time introduces refracturing overview to Kazakhstan's readers in term of worldwide experience. Competitive commodity prices lead to a need for more cost-effective methods to manage reservoirs, and refrac is one aspect of optimization, ideally reducing costs by accessing more resources through existing wells. The first paper on refract is dated to 1973 in USA, and for that date more than 500 000 fracs were implemented, and 35% of that quantity was refracs. A lot of considerations are given in terms of technology since that dates, such that conventional hydraulic proppant fracturing in existing well is now moving towards refracturing second, third and even fourth times to sustain economic production in mature fields. Our paper summarizes most relevant outcomes from the industry experience on proppant refracturing methods over last several decades. This is believed that readers would gain most valuable information for their research, industry problems, and other cases from this review paper. A summary of published literature can provide a database of analog field cases to guide operators in design of refract treatments.

KEY WORDS: *proppant hydraulic fracturing, re-fracturing, production enhancement, bottomhole formation zone.*

ОБЗОР КЛЮЧЕВЫХ ПАРАМЕТРОВ ТЕХНОЛОГИИ ПОВТОРНОГО ПРОППАНТОВОГО ГРП

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Данная статья впервые представляет казахстанским читателям обзор повторного ГРП с точки зрения мирового опыта. Конкурентоспособные цены на сырье приводят к необходимости более экономичных способов управления пластами, а повторный гидроразрыв пласта является одним из аспектов оптимизации, в идеале сокращая затраты за счет доступа к большему количеству ресурсов через существующие скважины. Первая статья по повторному ГРП датирована в 1973 году в США, и даже на тот момент было проведено более 500 000 ГРП, 35% из которых были повторные ГРП. С тех пор было дано много соображений с точки зрения технологии, например, обычный гидроразрыв с проппантом в существующих скважинах в настоящее время движется к повторному ГРП во второй, третий и даже в четвертый раз для поддержания экономичной добычи на зрелых месторождениях. В нашей статье обобщены наиболее важные результаты отраслевого опыта методов повторного ГРП с проппантом. Предполагаем, что из этого обзора читатели получат наиболее ценную информацию для своих исследований, проблем отрасли и других случаев. Сборник опубликованной литературы может предоставить базу данных аналоговых полевых примеров, которая поможет операторам при разработке методов повторного ГРП.

КЛЮЧЕВЫЕ СЛОВА: *проппантный ГРП, повторный ГРП, интенсификация добычи, призабойная зона пласта.*

ПРОППАНТЫ ГИДРАВЛИКАЛЫҚ ҚАЙТА ЖАРЫЛУ ТЕХНОЛОГИЯСЫНЫҢ НЕГІЗГІ ПАРАМЕТРЛЕРІНЕ ШОЛУ

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Бұл мақала алғаш рет қазақстандық оқырмандарға әлемдік тәжірибе тұрғысынан қайталанған гидравликалық жыртуларға шолу жасайды Бәсекеге қабілетті шикізат бағасы қабаттарды басқарудың үнемді әдістеріне қажеттілікті тудырады, ал сыну оңтайландырудың бір аспектісі болып табылады, бұл бар ұңғымалар арқылы көбірек ресурстарға қол жеткізу арқылы шығындарды азайтуға мүмкіндік береді. Гидравликалық жырту туралы алғашқы мақала 1973 жылы АҚШ-та пайда болды, тіпті сол уақытта 500 000-нан астам сыну операциялары жасалды, оның 35% -ы сыну болды. Содан бері технологиялық тұрғыдан көптеген ойлар қарастырылды, мысалы, бар ұңғымалардағы кәдімгі проппантпен жарту енді жетілген кен орындарындағы үнемді өнімді сақтау үшін екінші, үшінші және тіпті төртінші рет қайта жаруға көшуде. Біздің мақалада проппантпен жырту әдістерінің салалық тәжірибесінің ең маңызды нәтижелері жинақталған. Бұл шолу оқырмандарға олардың зерттеулері, салалық мәселелер және басқа да жағдайлар үшін ең құнды ақпаратты береді деп саналады. Жарияланған әдебиеттер жинағы операторларға гидравликалық жырту әдістерін әзірлеуге көмектесу үшін аналогтық өріс мысалдарының дерекқорын қамтамасыз ете алады.

ТҮЙІН СӨЗДЕР: *проппант гидравликалық жырту, қайталанатын гидравликалық жырту, өндірісті ынталандыру, қабат маңы аймағы.*

Introduction. Hydraulic fracturing by its own is one of the most widespread technologies to increase production from existing wells. But a lot of reasons appear to influence performance of the outcomes of provided hydraulic fracturing. Some of them include degradation of proppant pack, lack of initial proppant placement, deviations from design parameters during pumping operations, etc. To overcome such cases a refracturing is required. [Coulter et al. 1973] provided one of the first research on refracturing technology, where it was stated that more than 500 000 fracs were executed and 35% of these jobs were refracs [1]. [Vincent et al. 2010] provided an excellent overview of situation of refracturing technology in various cases [2]. Re-fracturing is estimated to be around 40% to 50% of the cost of fracturing a new well, and industry research reveals this cost is going down year on year [3]. From these researches it is obvious that refracturing is an alternative method to increase stimulation reservoir volume and gain additional production from existing hydraulically fractured wells.

In current paper a systematic basis on hydraulic proppant refracturing was summarized, so that advantages and disadvantages, candidate selection, design basics, diagnostic techniques were included into figures and tables with respectful references. This approach is believed to be useful in terms of a guideline when a dedicated job is planned on existing wells, so that previous world class experience is used.

Advantages and disadvantages of refrac treatments. Based on principals of hydraulic fracturing design, parameters, and behavior a comprehensive refrac parameters would be a key factor that need to be considered while any refrac is planned. Pros and cons of refrac are the one of main considerations prior a technology selection. This is supported by *Figure 1* of advantages and disadvantages of refrac treatments.

Candidate selection guidelines. Candidate selection is expressed in terms of the potential for stress reorientation, the quality of the initial completion, the initial production decline rate, the reservoir depletion around the well, or a combination of these. However, application of these methods remains limited, and results appear less than satisfactory in horizontal well or complex fracture network cases, or when adequate completion and reservoir data sets are lacking. Numerical simulation methods of well performance evaluation that consider the impact of natural fractures along with the presence of a complex induced fracture network arising from the initial hydraulic fracture completion are aids to understanding. Selection of the candidate well and the time of refracturing can be made using a thorough numerical simulation study developed by modeling of hydraulic fracture and the refrac process within the context of the specific project that accounts for the well's unique conditions (geology, geometry, completion, and production history).

It appears that candidate selection methodologies have focused primarily on underperforming wells. This simplistic approach has yielded disappointing results and has led to a common misconception that restimulations "don't work". Production statistics of a well alone may not offer an effective restimulation candidate selection methodology. Other parameters such as high BHP (remaining reservoir energy), and recoverable reserves, and favorable response to original fracture jobs (initial production) can play important roles in estimating the potential success of restimulation. In fact, studies have shown that selecting poor or underperforming wells for restimulation is

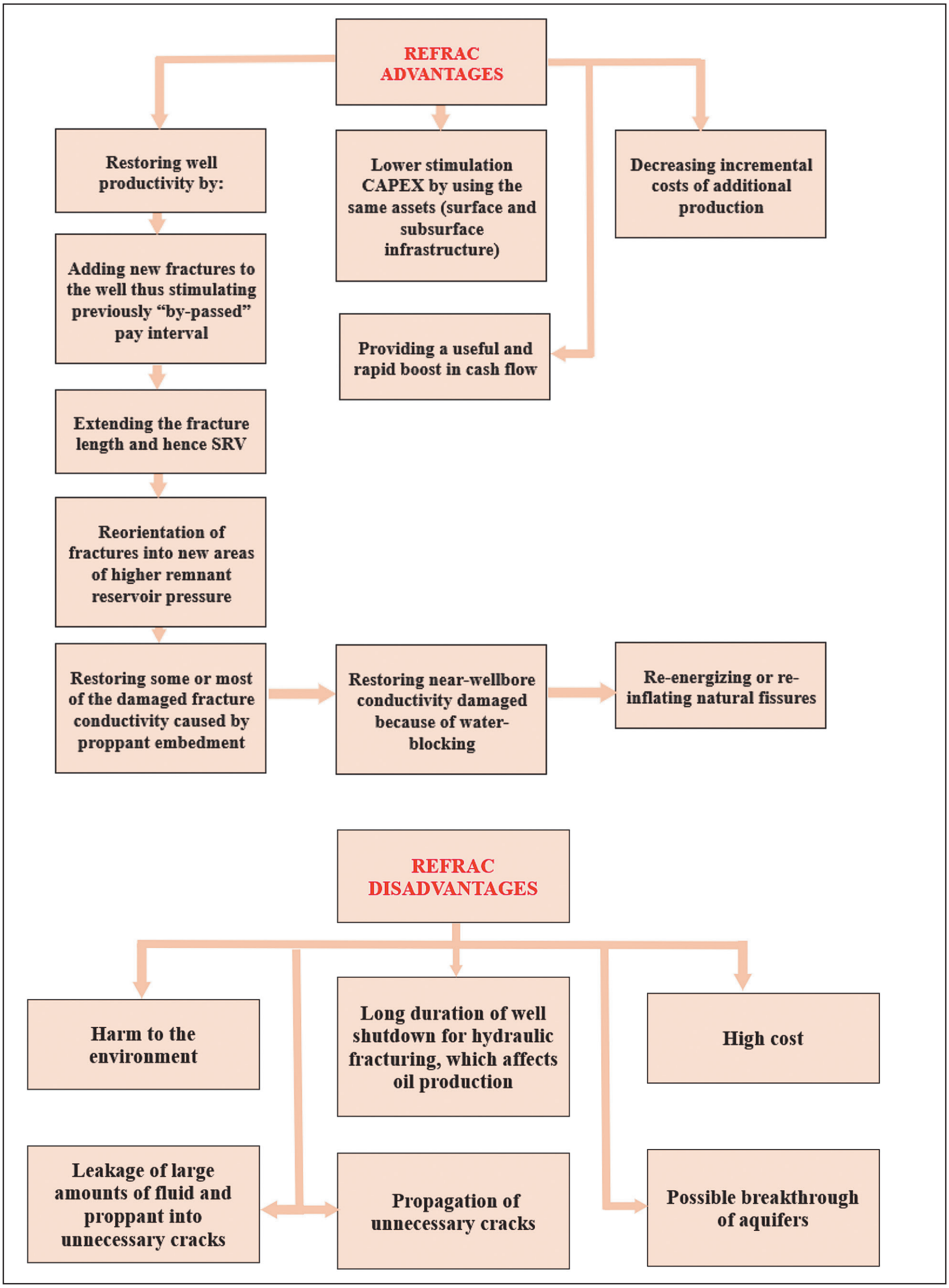

Figure 1 – **Refrac advantages and disadvantages [Wang Y][4]**

likely to result in worse outcomes overall. Several groups have suggested different methodologies for candidate selection and ranking (*Figure 2*) [5, 6].

Several candidate selection data sources may be considered:

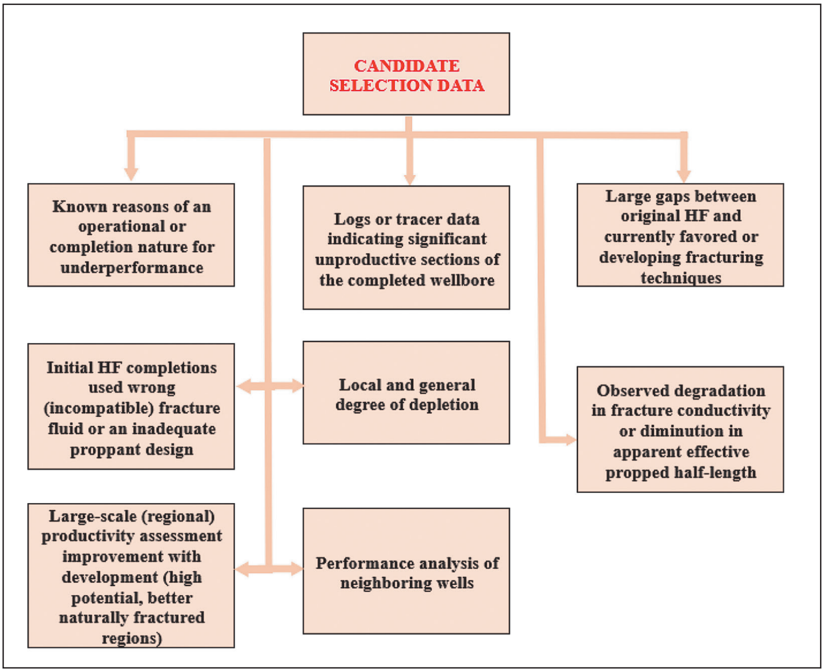

Figure 2 – **Candidate selection data [compiled by the authors]**

Design of refrac considerations. Simultaneous screening should be implemented on design factors, since both are interconnected. Since the introduction of conventional proppant fracturing a huge database was gathered worldwide to properly design the jobs. The same applies to refracturing. Comprehensive analysis of related literature revealed the following outcomes given in *Table 1*. Key design factors affecting on refrac include proppants and its placement, fluid systems, job volume, fracture geometry, pressure regimes, isolation methods, and other.

Table 1 – **Design of refrac considerations**

#	Key factors affecting Refrac	Comments
1	Proppants, proppant conductivity, proppant volumes, proppant concentrations, proppant durability, fracture width with proper proppant.	1. Optimization of Kuparuk field involved switching to light weight ceramic proppants, then to progressively larger proppant sizes, higher concentrations, and reduced pad sizes. A systematic reduction of silica flour, 100-mesh sand and other damaging fluid loss additives also served to improve retained fracture conductivity [7]. 2. There is no a field trial specifically evaluating whether more durable proppants will avoid or delay the need for restimulation, thus increased productivity cannot be confidently attributed solely to proppant durability instead of an overall increase in fracture conductivity [2]. 3. Extensive research of Bagzis indicates that lower sand concentrations resulted in steeper production declines, attributed to crushing and embedment of the frac sand [8]. 4. Numerous refracs were documented with proppant concentrations reaching 10 ppg, often achieving 3-4-fold increases in production in Cotton Valley [9]. Fleming reported that at depths down to 3000 ft, an increased proppant concentration (natural sand) and big particle size (12/20 mesh) allowed to increase production 6 times per well. 5. Salem formation with 0.5 mD was refracked with increased proppant concentrations up to 14 ppg of 10/20 sand, combined with forced closure, strategic use of 100 mesh sand, and lower injection rates. This provided increase in production from 3 to 750 bopd for more than 4 months [10].

Table 1 – **Design of refrac considerations**

2	Frac Fluids	1. Initially water based frac fluid were used in Viking formations in Canada and well were suffered from early screenouts and poor load recovery and were considered for abandonment. Refrac treatments with oil-based fluids and larger proppant volumes resulted in excellent load recovery and sustained production rates [11]. 2. Initial frac treatments with low proppant concentration in water-based fluids showed poor results in one of fields. Later gelled hydrocarbon fluids carrying up to 17 ppg concentrations reached better results, achieving remarkable increases in oil production [12]. 3. The initial treatment in Barnett Shale was with crosslinked gel, that resulted in microseismic activity predominantly confined near the wellbore axis. However, a subsequent refrac using slickwater was observed to induce microseismic activity over a larger reservoir area and provided significant increase in gas production rate; Godell restimulations with a reduced polymer CMG (carboxymethyl guar) fluid provided approximately 200% rate of return, compared to 66% with previous fluids; Comparing 479 recent restimulation treatments, fracs utilizing lower polymer CMG with cleaner base water typically increased pre-refrac rates by 500% [2].
3	Job Volume	1. Larger refrac treatments were often more productive in Muddy J-formations [13]. Ennis provides a good statistic on how production has been increasing based on several refrac on a single well in tight gas field. This clearly indicates that the enlarge volumes of treatments helped to sustain production [14].
4	Fracture length	1. Refrac success was largely attributed to extension of fracture half-lengths during restimulation [15]
5	Fracture height	1. In case of undesirably fracture grow out of zone in initial treatments because of weak stress barriers, it is required to consider reservoir pressure decline for re-frac. If pressure is declined, then possibly less net pressure would allow for fracture vertical growth containment. Some sand lenses in the heterogeneous pay zones were not fully stimulated vertically, and those lenses were chosen and refrac candidates - 22 wells were sidetracked or redrilled with cemented casing and stimulated, increasing reserves successfully [16].
6	Fracture reorientation	1. Examples of azimuthal reorientation of fracture have been demonstrated in many papers. The tendency of fractures to grow toward high stress may induce refracture treatments to become "reserve seeking missiles" as they may reorient toward higher stress, undefined regions of the reservoir [2].
7	Old proppant displacement	1. In case of old proppant placed in unsatisfactory mode, possible solutions should be to consider old proppant displacement by diversion methods [17].
8	Pressure regime	1. Cramer reviewed nine restimulation treatments, noting that the only failures were two wells that failed to energize the frac fluid with CO2 and N2, perhaps indicating the gaseous phase reduced formation damage and/or improved cleanup and recovery of the water-based fracturing fluid [2].
9	Previous treatments redesign	1. It should be kept in mind, that as technology develops, thus a new redesign strategy should be considered for initially treated wells [2].
10	Retrievable bridge plug	1. To isolate the treated zone, and treat the untreated zone [18]
11	Coiled tubing with isolation packers	1. When bypassed pay intervals are located between existing perforations, coiled with isolation packers or seal assemblies can be used to selectively isolate and restimulate desired intervals. Or casing liners may be preferred [2].

Diagnostic techniques for prior and after refracturing evaluation. Fracture diagnostic techniques are the key elements while candidate selection and design of refracs. Methods such as PLT, detectable proppants, tilt-meters, DFIT, microseismic mapping, selective isolation tests are amongst the primary tools to quantify refrac candidates and design a complex refrac jobs. *Table 2* represents the list of this methods, and dedicated proves and recommendations.

Table 2 – **Diagnostics techniques for prior and after refracturing evaluation**

#	Parameters	Comments
1	Breakdown pressure and other parameters from mini-frac DFIT	1. The effect of depletion was observed in the treating records, as breakdown pressure average 669 psi lower than initial treatment (Lantz, 2007); i.e. recording Breakdown pressure of initial and refrac treatments could reveal the further decisions on design [19].
2	PLT	1. Running PLT before and after refrac is a good tool to find out proppant distribution, particular in horizontal wells [20].
3	Detectable proppant logging	1. One proppant supplier can coat proppants with a resin containing taggant that can be made temporarily radioactive during logging to avoid handling radioactive materials at surface. Another ceramic manufacturer provides proppant in which an entirely non-radioactive material is permanently incorporated in each proppant pellet that can be detected with standard neutron logs [2].
4	Tilt-meter	1. Recommended method for fracture orientation identification [2].
5	Microseismic mapping	1. Good tool for fracture growth definition [2]
6	Selective isolation	1. Practical way to selectively identify and treat the zones [2].
7	Radioactive tracer	1. Without the diagnostic tracer, it may not have been possible to determine which intervals were poorly stimulated, and the operator may have attempted to restimulate the entire well, requiring a larger, more expensive treatment with little assurance of effectively treating the upper three intervals [18]. In Elm Coulee field the radioactive tracers were utilized to determine whether portions of the wellbore were unstimulated by the original treatment. Based on the log it was decided to add additional perforations with consequent refrac [19].

Results and discussions. Based on comprehensive literature review a systemized set of parameters were chosen to be considered while candidate selection, fracture design, diagnostics dedicated to refracturing technology. Figure of advantages and disadvantages was provided which could be useful prior any refrac job even started in mind. The authors independently compiled a figure of the classification of the candidate selection data. The following summary is the outcome of the review:

- Candidate selection criteria should be based on:
  - o Permeability, porosity, natural fractures, previous well history, reservoir pressure, reserves, well age; frac sand used initially; perforation intervals; knowledge on restimulation of cemented laterals; conductivity, concentrations; well shut-in before refrac; premature screenouts history; overflushed fracs history; pay zone coverage targets; previously small frac lengths, i.e. geometry; fracture containment; and refrac more than one time.
- Design criteria is recommended based on below parameters:
  - o Proppants, proppant conductivity, proppant volumes, proppant concentrations, proppant durability are amongst the main parameters; fracture width, fracture length, fracture height; frac Fluids; job volume; fracture reorientation; old proppant displacement; pressure regime; previous treatments redesign; retrievable bridge plugs; coiled tubing with isolation packers.

- Diagnostics should be planned and the following are the one of the main techniques:
  - Mini-fracs and related outcomes (DFIT); Production logging tools (PLT); Detectable proppant logging; Tilt-meters; Microseismic mapping; Selective isolation; Radioactive tracers.

Conclusion. In this paper, reviewed refrac advantages and disadvantages, candidate selection guidelines, design of refrac considerations, and diagnostic techniques for prior and after refrac evaluation. This article describes to why re-fracturing works and the exact conditions that exist which ultimately make the mechanism of re-fracturing successful.

The authors analyzed 20 bibliographic sources, and independently compiled a figure of the classification of the candidate selection data. The main trends and factors were the correct choice of candidate selection criteria, design of refrac considerations, and the correct techniques for prior and after refrac evaluation. These approaches is believed to be useful in terms of a guideline when a dedicated job is planned on existing wells and these results have broad applied significance and can actively use when carrying out hydraulic re-fracturing on wells.

To summarize, we can say that hydraulic re-fracturing is the most effective way to intensify a well. Today, not only hydraulic re-fracturing is carried out, but the wells are also being fractured for the third time. This suggests that the method of proppant re-fracturing is the most in demand.

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