Effect of Re-fracturing on Production Profile in Shale Gas Well

by

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14181

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Petroleum Engineering Programme

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Approved by,

____

(Mr. Syahrir Ridha)

Universiti Teknologi PETRONAS

TRONOH, PERAK

SEPTEMBER 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein has not been undertaken or done by unspecified sources or persons.

Sherzod Kamilov

ABSTRACT

Over the decades, the hydraulic fracturing was used as the stimulation technique for oil and natural gas production enhancement. Hydraulic fracturing is the technique to retrieve the production of the formation.

The new approach of stimulation was brought to oil and gas industry in order to enhance the production more effectively using re-fracturing method. Re-fracturing is relatively new technique which intrigued the oil and gas operators with potential success in stimulation. This case study was performed on real life Barnett and Woodford fields in order to discover how the re-fracturing impacts the production profile. By studying the specific treatments of the re-stimulation techniques and production data sets of other fields the outcomes of the study were also considered to obtain the concepts to how shale plays should be treated. In this case study both initial fracturing and re-fracturing operations were taken into account. The impact of these operations was analyzed on long term recovery. The other related available data and materials from other identical fields were also considered and analyzed for further investigation. The discussion also includes the well selection processes, re-fracturing approach and resulting improved production profiles.

However, the primary steps and operations were practiced in oil fields by Iranian companies, but the results were unproductive because of the improper candidate selection method of the wells for re-fracturing. There is no standard procedure to select the primary candidates. However, several factors are taken into account for Selection Method.

Several real life field operations, which involve the candidate selection for re-fracturing the wells, were studied. The selection method was based on the Fuzzy logic and Neural Network technique. The selection goes through a group of parameters having selection of the target formation, as well as different attributes and features, such as: geological aspect, reservoir and fluid characteristic (Abolfazl et al., 2013; Mansoor et al., 2013; Shahab et al., 2000). Such complex procedure, methodology and the logic behind that approach will be covered and discussed further. The utilization of such problem-solving tool can be considered as a great concern in the future.

ACKNOWLEDGEMENT

I would like to take this opportunity to express my utmost appreciation and gratitude to my supervisor, Mr. Syahrir Ridha for benevolent guidance and support, and trust he put in me that helped complete my project successfully.

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CHAPTER 1

INTRODUCTION

1.1 Background Studies

In 1996, the Gas Research Institute (GRI), further renamed as Gas Technology Institute (GTI), started to evaluate re-fracturing as a cost effective in enhancing the gas production and adding recoverable reserves (Shahab et al., 2000). The prior evaluation found essential onshore gas potential of more than 10Tsf (286.4 billion m^3) of gradually increasing reserves in the USA.

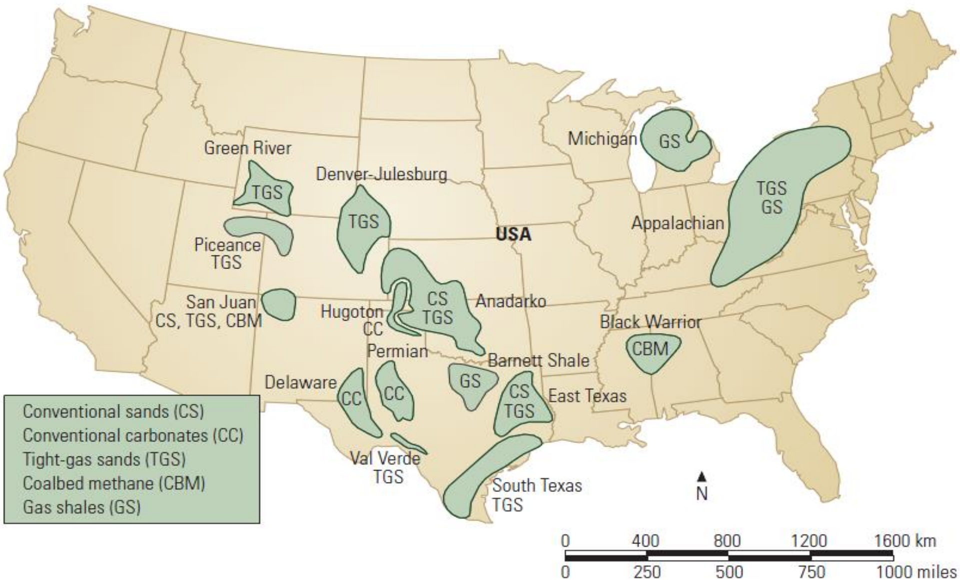

Figure 1.1: Areas with re-fracturing potential in the USA. (George D. et al., 2003)

Oil and Gas Industry has put great effort to increase the rate of recovery in mature fields, because it is becoming challenging to find new reserves and the recent hydrocarbon prices are increasing. Based on Ruckheim (2005), the average rate of recovery 35% for oil and 70% for gas, but oil and gas industry is planning to make the rate of recovery 50% and 80% for oil and gas respectively. Hydraulic Fracturing has contributed significantly to oil and gas industry since it was developed (Veatch et al., 1989). However, for more effectiveness the re-fracturing treatment was brought and in order to success in it three critical parts should be considered: candidate well selection, treatment design and field operation (Mansoor et al., 2013).

These three criteria's are known as productivity triangle and they share the responsibility in order to success or fail in re-fracturing treatment.

Gas Research Institute (GRI) believes that Candidate Well Selection phase is where the greatest industry benefit resides and many stimulations fail because of poor-candidate selection (Ely et al., 2000). It has been noticed that the success of re-fracturing treatment increases with the improvement of the selection method (Vincent, 2011; Guoynes et al., 2000). Thus, the selection of appropriate well or formation is a matter of importance.

There are huge amount of parameters that must be considered prior to performing the operation. According to Shadizadeh and Zoveidavianpoor (2010) Zoveidavianpoor et al. (2011a)., the lack of data such as: rock mechanical properties, regional in-site stress, and especially absence of consideration of candidate selection study, are the general reasons of failure. Southern Iranian field operations show that to accept the re-fracturing technology as stimulation method as well as increasing the recovery factor, the most effort should be addressed to the zone and well candidate selection.

However, the successful goals of re-fracturing have tempted the oil and gas operators for 50 years. Most interesting thing is that, this method can either re-establish or increase the well productivity under certain conditions, yielding the more reserves by improving hydrocarbon recovery. Approximately, 70,000 of newly drilled wells every year represent only 7-8 % of the total number of producing wells in the world (World Trends, 2003).Thus, taking as much output as it is possible from over 830,000 initially completed wells is important for field development, production enhancement and reservoir management. Even the lowest production increases from the portion of the large number of existing wells represent essential incremental reserve volumes. Re-fracturing method helps to realise this objective.

Every shale reservoir is unique. Two different shale reservoirs, Barnett Shale and Woodford Shale, were studied for further comparison of the results. The zone selection and the properties of the re-fracturing method, which can contribute to the success in production rates in these fields, are considered as a long term objective. The parameters and categories of candidate selection for re-fracturing the well, the techniques and approaches for re-fracturing operations were studied during the research. The outcomes and the results of the case study based on the real life field operations can serve as the guideline for future usage of this method in shale gas wells with identical formations.

1.2 Problem Statement

Re-fracturing can produce higher conductivity propped fractures that may permeate deeper into a formation comparing to initial treatment. However, not all re-stimulation are efficient to re-establish the productivity. Some wells with sufficient production rates also can be good candidates for re-fracturing. In fact, good productive wells in the fields have highest re-stimulation potential (George D. et al., 2003). However, many companies unwilling to conduct re-fracturing treatments on wells which produce at economic rates. The aspiration is not to re-fracture any wells, or to re-fracture only poorly performing wells.

Re-fracturing operations tempt to improve the productivity of the well. However, despite documented successes in individual wells and several field-wide re-fracturing efforts, some operators indicated disenchanted results when re-fracturing previously stimulated wells (Sharon Y. W., et al. and Parrot D. I., et al.).

The lack of understanding of re-fracturing mechanics and other aspects, as well as the lack of experience in using this method making it to have negative preconceptions about re-fracturing method.

The oil and gas industry’s current experience with re-fracturing is mixed and it is believed that the reason for the failure of this method of stimulation is lack of both specialized in re-fracturing method and not proper candidate selection focusing on re-fracturing method (Shahab et al., 2000).

1.3 Objectives

The objectives of this study are:

- to study the parameters and criteria's of candidate selection for re-fracturing
- to develop reliable methodology to conduct successful candidate selection
- to compare the production profile before and after re-fracturing and analyse the effect on production profile

1.4 Scope of Study

The overall research plan is to perform case study on different real life field operations and compare the production profile before and after re-fracturing method was used. Subsequently the impact of re-stimulation, key parameters of candidate selection, and the technical approaches will be analyzed.

The different methodologies will be considered and briefly explained. However, the case study methodology, regarding the selection of the candidates, will be focused on the Neural Network and Fuzzy Logic.

Based on this analysis, an optimized approach for production improvement can be selected and will be proposed for future usage of the re-fracturing method with identical formations.

The overall research does not include the coding of neural network and fuzzy logic selection method.

CHAPTER 2

LITERATURE REVIEW

2.1 Shale Gas

Shale gas is a natural gas that is found trapped within shale formations. Shale formations are fine- grained sedimentary rocks which might content sufficient amount of petroleum and natural gas. When a shale formation is thermally mature enough and has sufficient gas content, it will produce natural gas.

Figure 2.1: Shale Formation (Retrieved from http://www.wikipedia.org/wiki/Shale).

2.2 Geology of shale

Most of the shales are not considered as commercial sources of natural gas. The reason for that is because it has poor permeability to allow fluid to penetrate into well bore. That makes the shale to be considered as unconventional reservoir. The main difference between conventional and unconventional reservoirs is, as mentioned previously, several orders of magnitude poor rock matrix permeability, substantially demanding stimulation for economic development. The area where a shale gas exists is called resource plays**.** The geological risk of having failure in finding the natural gas in these areas is as low as having potential profit from successful well.

The organic material (mature petroleum source rock, which are brittle and rigid enough to maintain open fractures) content in shales is significant (0.5%-25%), which are mature. The thermogenic gas window, with high temperature and pressure, turns the petroleum into natural gas.

Some amount of the produced gas is held in natural cracks, which is produced immediately. Also, some amount is devoured onto organic material, which is released as the formation pressure is drawn down by the well.

Shale has low permeability. In order to have commercial based gas production the fracturing is needed to provide sufficient permeability.

2.3 Hydraulic Fracturing

Hydraulic fracturing is a technique which involves the injection of more than a million gallons of water, sand and chemicals at high pressure down and across into horizontally drilled wells as far as 10,000 feet below the surface. The pressurized mixture causes the rock layer to crack. These fissures are held open by the sand particles so that natural gas from the shale can flow up the well.

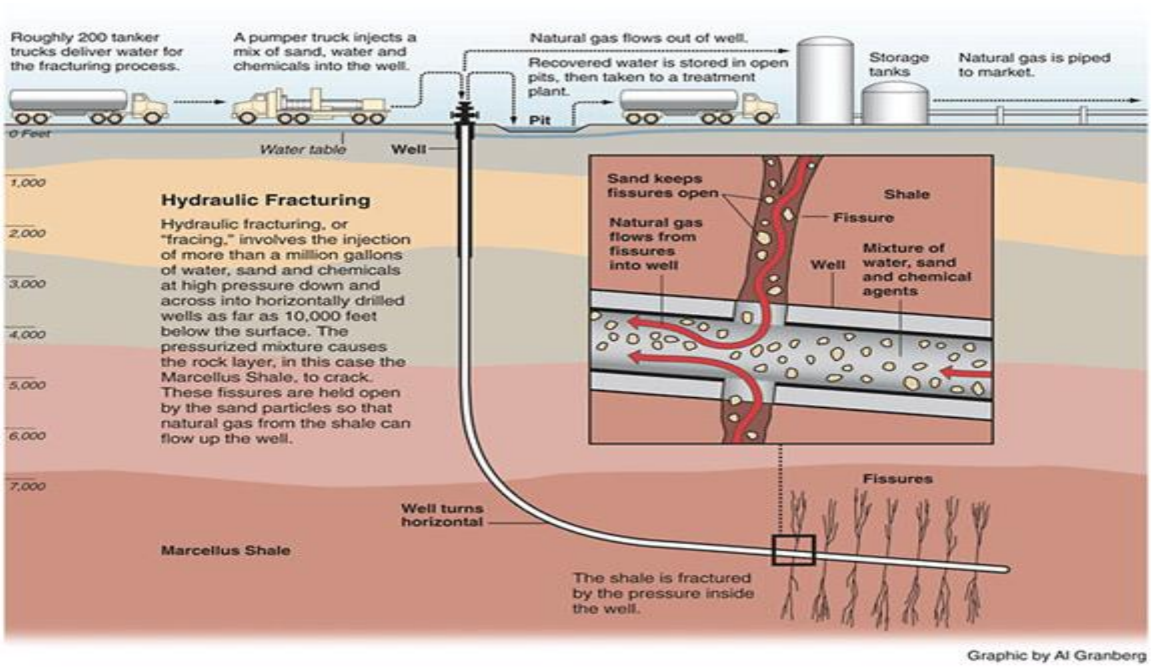

Figure 2.2: Hydraulic Fracturing Schematic. (Retrieved from http://www.propublica.org).

In order to make ultimate borehole surface area in contact with the shale, the horizontal drilling is usually utilized, where lateral length goes up to 10,000 feet (3,000 m) within the shale formation.

2.4 Re-fracturing

Re-fracturing was introduced to the petroleum industry in U.S. in 1950's, as well as in China in 1960's (Wang et al., 1998).

Over 30% of fracturing operations were conducted on the older wells. Most of them are the completions of new intervals; the rest are the treatments on producing zones without initial fracturing or a mixture of new intervals and older under stimulated or unstimulated zones. The treatments involve re-fracturing older stimulated intervals after initial period of production, reservoir pressure drawdown and partial depletion.

Re-fracturing is the process of a well re-stimulation after initial production period. This operation tempts to bypass near-wellbore damage, restore the good link with the reservoir, and penetrate the parts of the reservoir with sufficient pore pressure. Re-fracturing can also be conducted after production period which can cause to adjust the stresses beneath the reservoir due to depletion; the re-fracturing can redirect the new fracture along the dissimilar azimuth. The productivity can either be restored close to the initial production rate or can even be improved to higher production rates, as well as the production life can also be extended during the re-fracturing operations.

This method is effective in low permeability, naturally fractured, laminated and heterogeneous formations, especially gas reservoirs.

2.5 Candidate Well Selection for Re-fracturing

There are many factors to be undertaken prior to re-fracturing operation. It is sufficient to select the wells with the highest potential of improvement after stimulation due to the availability of the finite financial resources in each re-fracturing treatment. In order to be successful in re-fracturing treatment, the fluid (gas) must be produced at a higher rate than before the treatment. In order to achieve that aim, the reservoir must have sufficient hydrocarbon in place, as well as the potential gradients must be good enough to move the fluid to the wellbore after the re-fracturing took place (Howard and Fast, 1970).

Candidate well selection mainly deals with engineering, and geological aspects in decision making process and involves high importance in order to increase the performance of the advanced techniques. The list of parameters that used by literature of candidate well selection are stated in the table below.

Table 2.1: List of parameters that are considered during candidate well selection in different literatures

Researchers/Methods	**K**	**S**	**h**	**P**	**Q**	**Φ**	**W**	**PI**	**SP**	**DA**	**OP**	**DC**	**FD**
Howard and Fast (1970)	*			*	*				*		*	*	
Bailey and Wickham (1984)	*		*	*		*							
Bustin and Sierra (2009)	*							*					
Smith (2006)										*	*		
Moore and Ramakrishnan (2006)	*		*			*				*			
Shadizadeh et al. (2009)	*					*	*		*				
Hashemi et al. (2012)	*	*	*	*			*						
Xiong and Holditch (1995)	*	*	*	*		*	*			*			*
Yin and Wu (2009)	*	*	*	*	*		*						
Yang (2009)	*	*	*	*	*	*	*						

(K=permeability; S=skin; h=pay zone thickness; P=reservoir pressure; Q=production rate; Φ=porosity; W=water cut; PI=production index; SP=stress profile; DA=drainage area; OP=offset production; DC=degree of consolidation; FD=formation depth)

CHAPTER 3

METHODOLOGY

3.1 Project Methodology

In order to get more information for better understanding and further investigation on re-fracturing the massive literature review will be done. The comparative case study based on the real life Barnett Shale and Woodford Shale fields, where the re-fracturing took place to see the effect on production profile, will also be conducted. Moreover, the candidate selection method will be studied to analyse the key parameters which plays significant role in selecting the wells to re-fracture. The other real life fields, which were using the re-fracturing method, will also be studied for further comparisons during the research.

3.2 Methodology on Fuzzy Logic and Neural Network

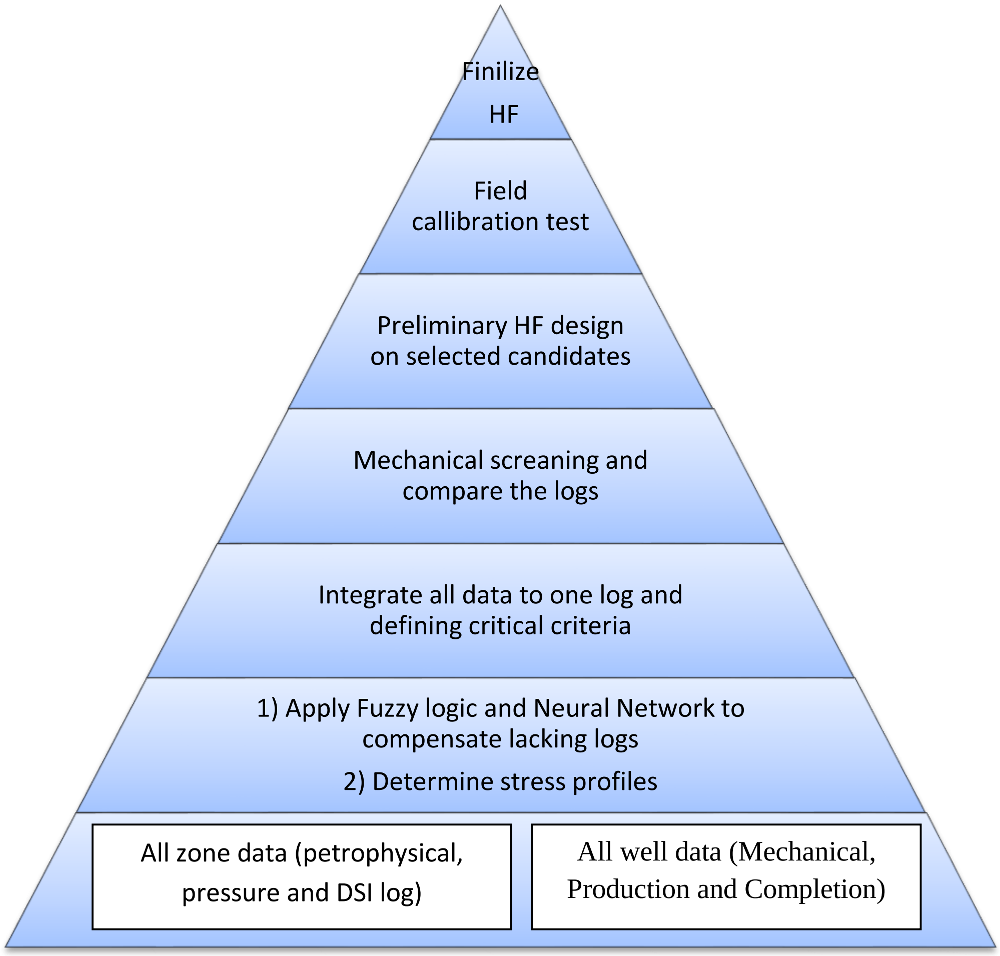

Figure 3.1: The procedure of the Fuzzy logic and Neural Network

The main procedure of the Neural Network and Fuzzy Logic candidate selection and screening is performed on two data sets. In of them, all zones are processed, where the second set is responsible well data examination. For zone selection practice, in the first step all data such as: log data, petrophysical data, bottomhole pressure, are collected in separate excel sheets with specified formats. One of the advantages of this method advantages is it can include any data which can be attributed to one zone: completion status, flow dynamic data.

Fuzzy Logic and Neural Network are utilized to train by available log data and spread correlated results to other wells.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Re-fracturing vertical shale wells (Barnett Shale)

Two hundred wells out of thousands were selected in the core area of the Barnett, because the location of the wells is one of the factors influencing production profile in Barnett shale. Most of them are the vertical wells spread cross Denton, Wise, Tarrant, Parker, and Johnson counties of the Barnett area. Table 4.1 shows the annual average production rates of these counties.

The highlighted counties have more production rate comparing to others. The reason of choosing this core area is to observe the reservoir quality on the success of production enhancement operations, which is considered as long term objective of the project.

Table 4.1: The annual average production rates (Sharon Y. W., et al., 2013).

	Bosque (MCF)	**Denton** (MCF)	Erath (MCF)	Hill (MCF)	Hood (MCF)	Jack (MCF)	**Johnson** (MCF)	Palo Pinto (MCF)	**Parker** (MCF)	Somervell (MCF)	**Tarrant** (MCF)	**Wise** (MCF)
Average Year 2010	5	2,567	137	221	605	148	2,754	126	974	68	2,574	2,265
Average year 2011	3	2,679	137	230	636	152	3,044	142	1,020	94	3,061	2,480
Average year 2012	1	2,727	132	228	661	158	3,161	143	1,049	96	3,373	2,558

171 wells were initially stimulated and completed before 2006 (mainly in between 2001 and 2003), which can be observed in Figure 4.1. Re-fracturing operations were conducted on different wells from 2002 until 2012 (Figure 4.2).

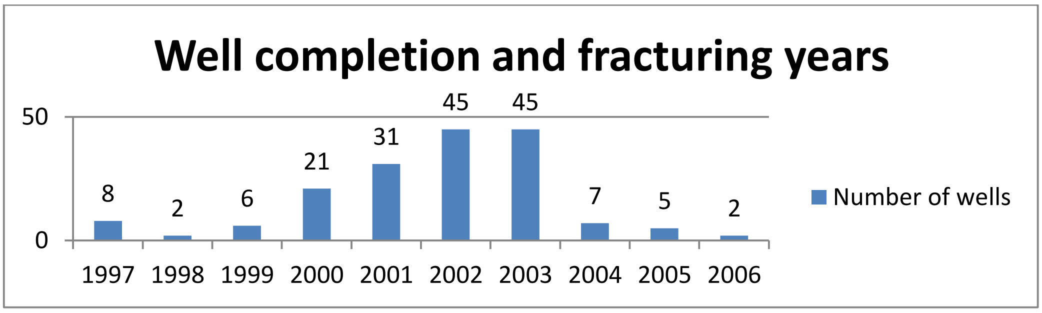

Figure 4.1: Initially completed and fractured wells in ten years (Sharon Y. W., et al., 2013).

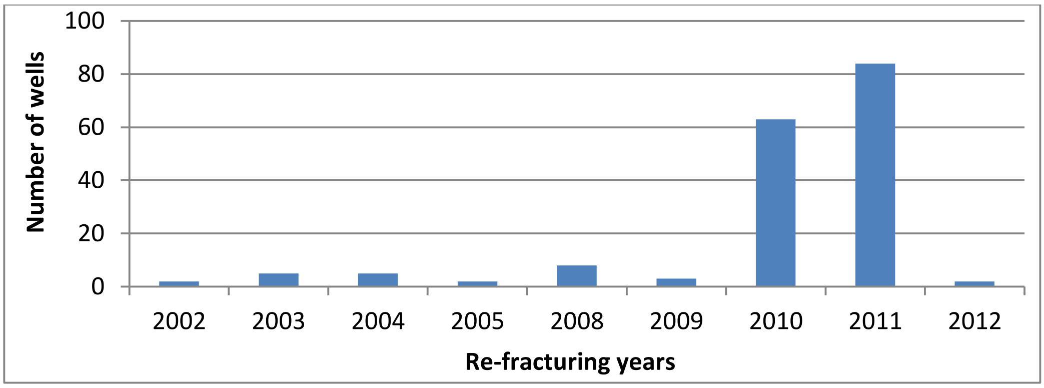

Figure 4.2: Well Re-fracturing in ten years (Sharon Y. W., et al., 2013).

Figure 4.3 illustrates the entire well's calculated 6 month cumulative gas production after initial stimulation, pre and after re-fracturing respectively.

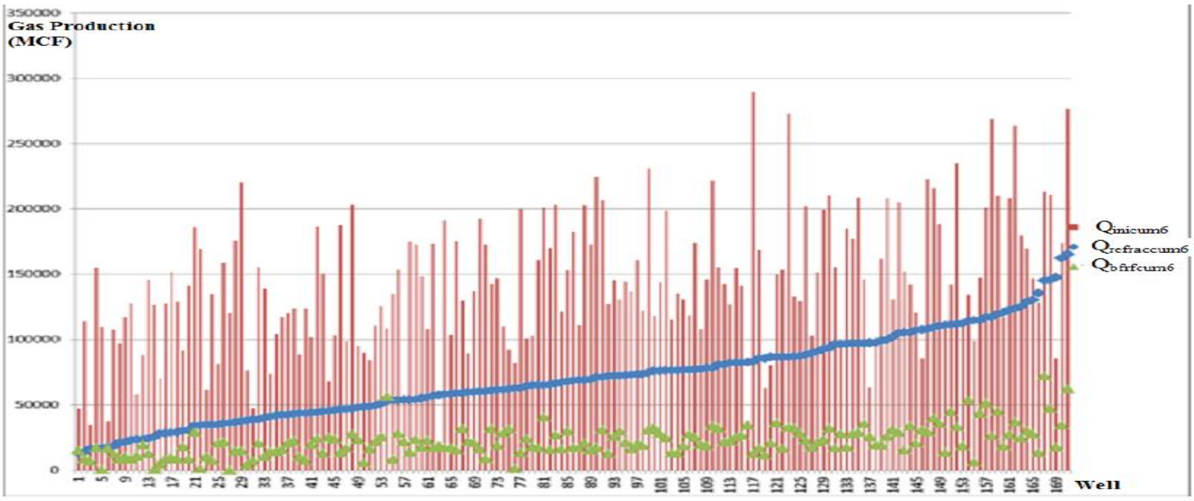

Figure 4.3: Six month cumulative gas production in three stages: initial (red columns), before re-fracturing (green triangles), after re-fracturing cumulative production (blue diamonds) (Sharon Y. W., et al., 2013).

The following terms were used during the calculations and plotting of the graphs and diagrams:

$Q_{inicum6}$ = Initial 6 month cumulative gas production, (Unit: MCF);

$Q_{bfrfcum6}$ = Cumulative 6 month gas production before re-fracturing, (Unit: MCF);

$Q_{refraccum6}$ = Cumulative 6 month gas production after re-fracturing, (Unit: MCF);

Q_{diff} = Production difference between before and after re-fracturing ($Q_{diff} = Q_{refraccum6} - Q_{bfrfcum6}$), (Unit: MCF);

$R_{decline}$ = Percentage ratio of cumulative 6 month gas production before re-fracturing to initial 6 month cumulative gas production ($R_{decline} = 100 * \{Q_{bfrfcum6}/Q_{inicum6}\}$);

R_{refrac} = Percentage ratio of cumulative 6 month gas production after re-fracturing to initial 6 month cumulative gas production ($R_{refrac} = 100 * \{Q_{refraccum6}/Q_{inicum6}\}$);

R_{jump} = Percentage ratio of cumulative 6 month gas production after re-fracturing to cumulative 6 month gas production before re-fracturing ($R_{jump} = 100 * \{Q_{refraccum6}/Q_{bfrfcum6}\}$)

4.1.1 Discussion on Barnett field operation results

Most of the well's 6 month cumulative production decreased in the range of 5-25% of the initial peak production (Figure 4.4). The production improved up to 50-70% of initial production (Figure 4.5). The production increased 2-4 times compared to the production before re-fracturing (Figure 4.6).

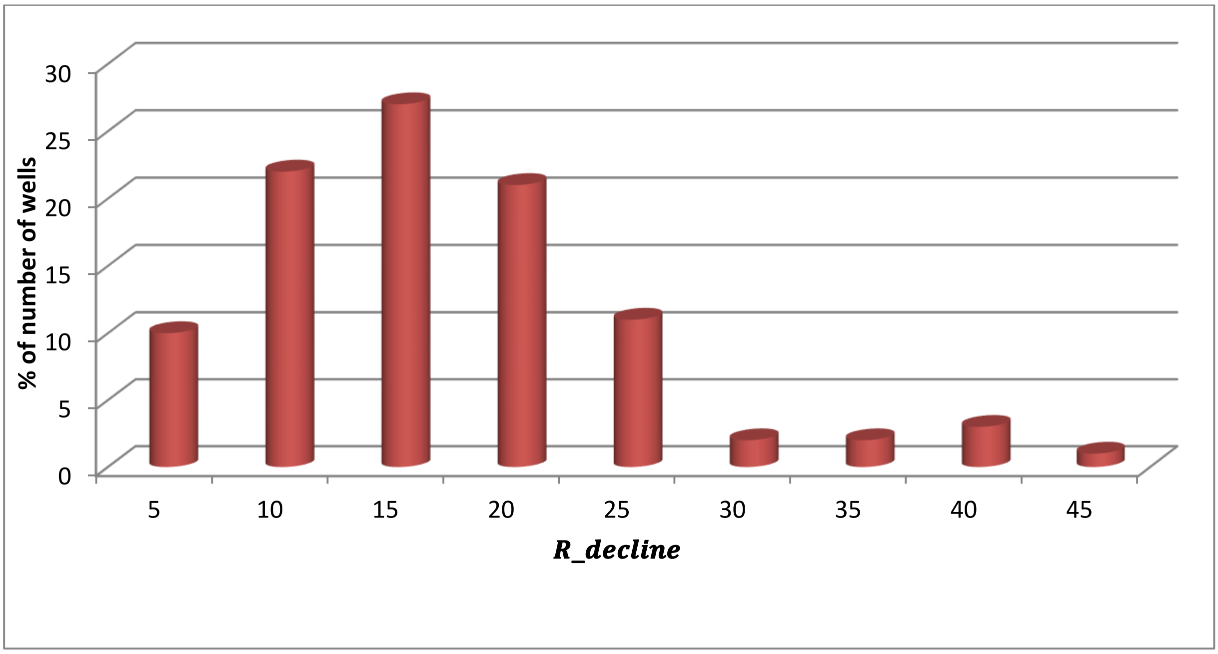

Figure 4.4: Percentage of number of wells vs.R_decline. (R_decline is percentage ratio of cumulative 6 month gas production before re-fracturing to initial 6 month cumulative gas production) (Sharon Y. W., et al., 2013).

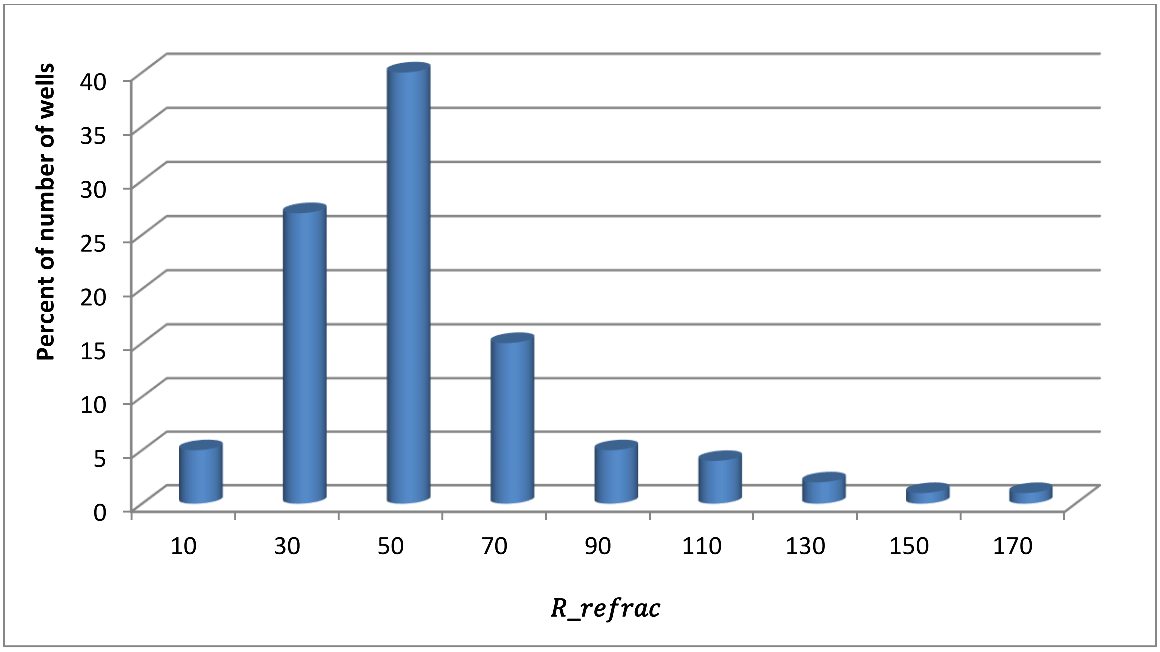

Figure 4.5: Percentage of number of wells vs. R_refrac. (R_refrac is percentage ratio of cumulative 6 month gas production after re-fracturing to initial 6 month cumulative gas production) (Sharon Y. W., et al., 2013).

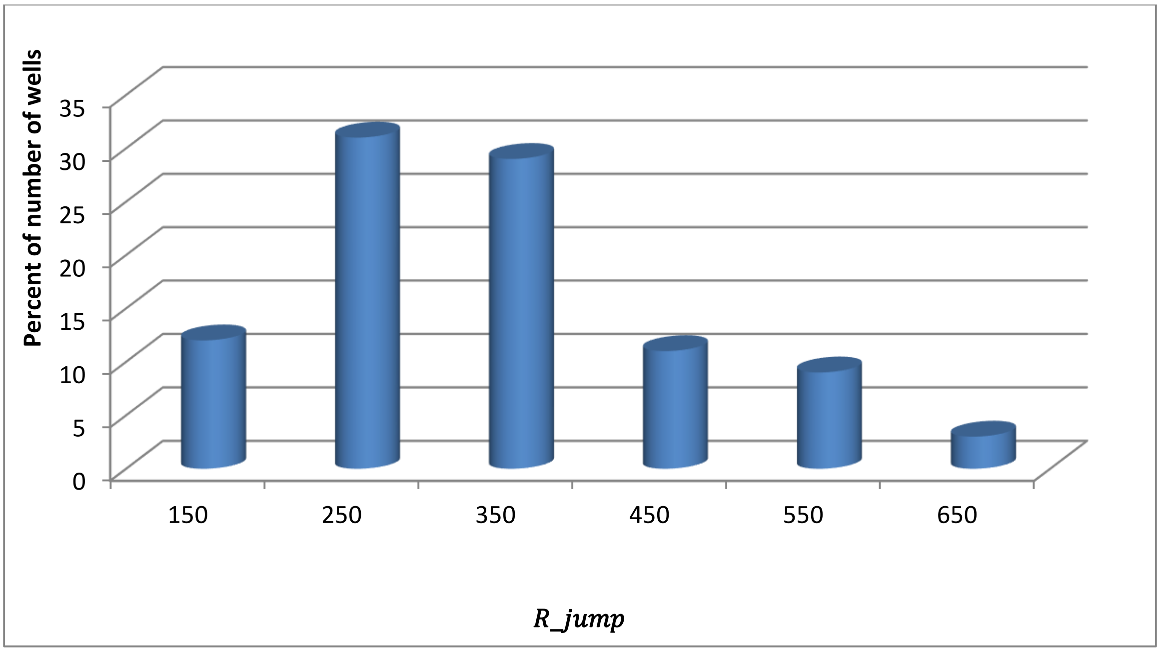

Figure 4.6: Percentage of number of wells vs. R_jump (R_jump is Percentage ratio of cumulative 6 month gas production after re-fracturing to cumulative 6 month gas production before re-fracturing) (Sharon Y. W., et al., 2013).

Considering 70 vertical wells, the injection rate had significant effect to the initial 6 month cumulative production during initial fracturing. While in re-fracturing operations the following factors effected the initial 6 month cumulative production: proppant mass, surface shut in pressure, pad volume, average surface treating pressure.

When the two horizontal wells were undergone re-fracturing, the cumulative production rate of the gas increased comparing to the production rate of the initial fracturing operations. However, the cumulative production results improved after re-fracturing on both vertical and horizontal wells, but did not overcome the initial cumulative production rate of the gas yet.

4.1.2 Treatment analysis

During initial fracturing and re-fracturing operations 79 out of 171 wells were undergone slick-water treatments. Nine out of 79 wells were either deviated or horizontal and 70 were vertical.

For initial fracturing operations the injection rate ranged from 50 to 80 bpm (Figure 4.7), whereas for re-fracturing operations the injection rate reached to 100 bpm (Figure 4.8).

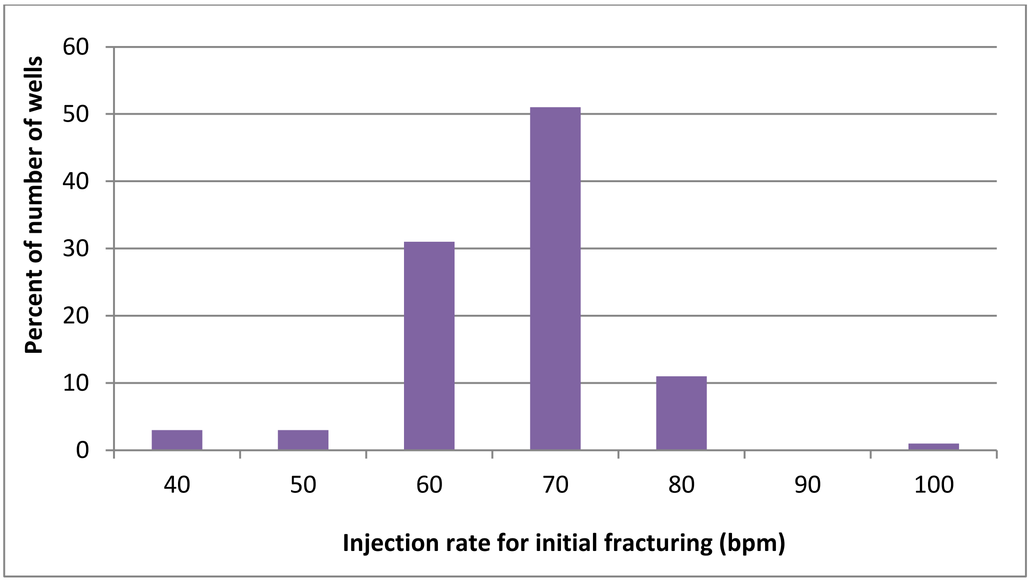

Figure 4.7: Injection rate for initial fracturing operations (Sharon Y. W., et al., 2013).

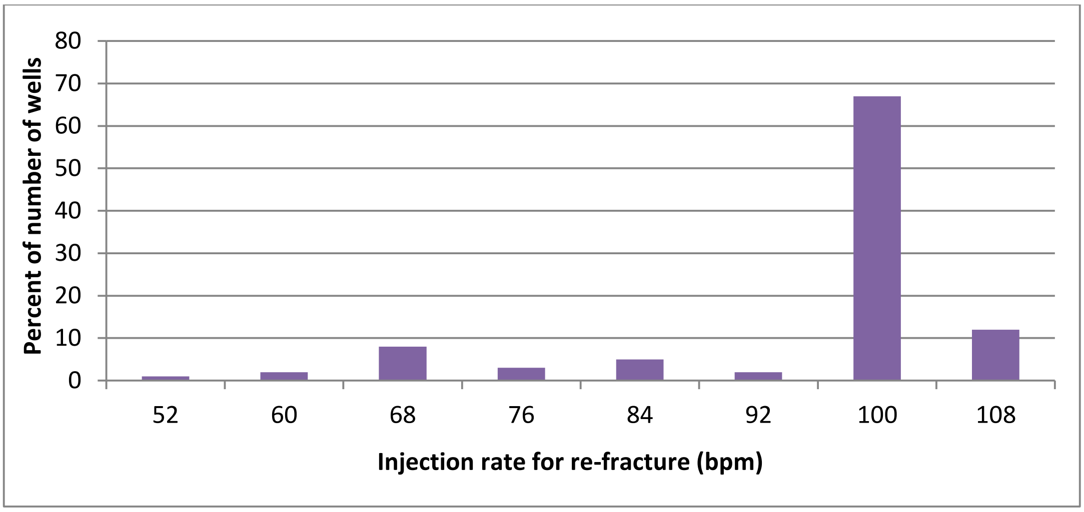

Figure 4.8: Injection rate for re-fracturing operations (Retrieved: Sharon Y. W., et al., 2013).

The proppant used during initial fracturing was 20/40 or 40/70 mesh white sand, and for re-fracturing 100 mesh white sand was used.

4.2 Re-fracturing horizontal shale wells (Woodford Shale)

The Woodford Shale is located in Hughes, Coal, Pittsburgh and Atoka counties of Oklahoma. The area which is operated by British Petroleum in Woodford Shale has very little water production and is considered a dry gas reservoir. The depth of the reservoir ranges from 6000 to 12000 ft. and the thickness varies from 50-300 ft. The initial gas in place is 40-120 Bcf/square mile. The re-fracturing operations are focused in horizontal wells in Woodford.

Four vertical wells were drilled in 2005 - 2006 and more than 60 horizontal wells were drilled in 2007 - 2008. When BP started their operations, another 90 horizontal wells were drilled and completed in 2009 - 2013. The studies showed success of two to four times in the initial production rate when many horizontal wells were re-fractured in Woodford area.

4.2.1 Discussion on Woodford field operation results

The wider stage spacing revealed that there was existing significant potential for un-stimulated rock volume. The Woodford Y1 well was completed in 2007 and was a dry gas well. It has a best quality of the rock in BP Woodford area, highest total organic carbon, thickest pay, higher pressure and higher matrix permeability. The proppant and the average liquid volume used were 30/50 Ottawa sand and 12000 bbls/stage of slick water beneath 4 stages. The initial gas production rate for 30 days of Y1 well was 3.4 mmscf/d and the cumulative production in a year was 1.7 Bcf, where the expected initial gas production rate for 30 days was 5.4 mmscf/d and the cumulative production was 2.4 bcf. The reason for that was inadequate proppant volume restricted the initial fracture conductivity. Considering all that the first four stages of Y1 well could be a good target for re-fracturing.

In order to determine the candidate wells for re-fracturing on horizontal wells in Woodford acreage the following summarized criteria's were taken into account:

- Single well in the section area in order to avoid fracture hits on other wells: it is believed that during re-fracturing operations the other adjacent wells are being less affected.
- The initial fracture stage spacing is more than 500 ft/stage: the new fracture stages between old ones are added to re-fracture un-stimulated areas.
- 30% or more of initial stages placed minimal proppant
- Low cumulative production
- Thick reservoir
- Rock quality
- High current reservoir pressure: low cumulative production, thick reservoir, rock quality and high current reservoir pressure are all important countable variables resulting in high Gas Initial in Place. High GIP is one of the important criteria's for re-fracturing economics.
- Production of gas rate is less than 700 mscf/d: to limit the risk of actually damaging production after re-fracturing the wells
- No perceived faults: in order to mitigate the risk of fracturing faulted zones

- Sufficient surface location size for fracturing operations: the location should be good for fracturing spread

The process of candidate selection of five horizontal wells of Woodford acreage is summarized as an example in the following table:

Table 4.2: Candidate selection process of five wells (French S., et al., 2014).

Wells	Single well in section	Fracture stage spacing (ft)	Original stage count (No)	Effective stage count (No)	Additional Pay (ft)	Cumulative production (Bscf) year	Net pay (ft)	Initial pressure (psi)	Before re-fracture gas rate (mscf/d)	Before re-fracture water rate (bwpd)	Best rock area (yes/no)
X-1	Yes	525	6	4	738	1.73	151	4348	550	4	Yes
Y-1	No	524	6	2	212	1.72	172	4237	300	0	Yes
Z-1	Yes	673	5	3	944	0.40	147	3420	100	31	No
A-1	Yes	496	6	4	0	2.27	174	5300	700	10	Yes
B-1	Yes	892	2	1	2910	0.38	164	2728	150	5	No

Four re-fractured wells were producing, and one (B-1) was going workover operations. The production results of four wells before and after re-fracturing are shown in Figure 4.9.

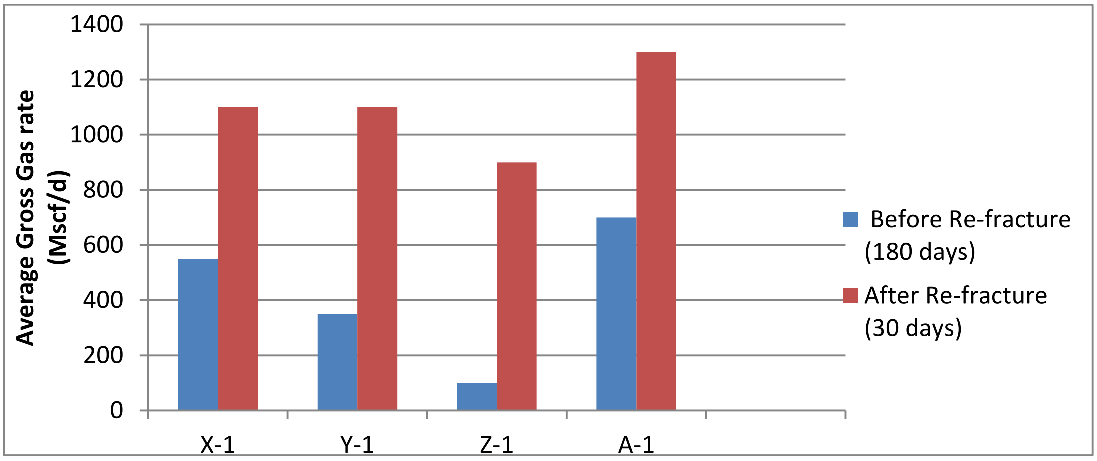

Figure 4.9: Production rates before and after re-fracturing (French S., et al., 2014).

The study showed that re-fracturing of horizontal shale gas wells can add gas rates and reserves. The wells which are situated in good area have more potential performance. The best rock quality and high GIP are considered in candidate selection. Higher initial production in a month indicates that the area of the well has good rock quality. The re-fracturing operations have lower impact of the fracture hits to the parent well.

4.3 Discussion on Candidate Well Selection using Neural Network Fuzzy Logic

The Neural Network was applied on X field. As the first step, neural network are used to build a representative model of the well performance. Numbers of parameters were used in neural network model building process, which are tabulated in Table 4.3.

The second step involves the optimization of the stimulation parameters using the parameters such as fluid type, total fluid volume and total proppant amount. The algorithm which was developed in the first step searches and tries to find the combination that result in highest five year cumulative production. This procedure is repeated for every well. The difference between optimized five year cumulative production and actual five year cumulative production is believed to be missing production which re-stimulation recovers.

Table 4.3: Input parameters for neural network

Category	Input parameter
Location	**x coordinates of the well**
	y coordinates of the well
	kb elevation
Reservoir	**permeability**
	drainage area
	total gas
Completion	**total completed thickness (all zones)**
	total number of perforation holes
	completion date
	number of zones
Frac	**frac number (up to 7)**
	fluid type
	fluid volume pumped in fracs
	proppant amount

The third step is fuzzy system. The parameters such as potential five year cumulative, fractures per zone and pressure are considered as inputs. It was observed that there are wells which were completed in all zones but one hydraulic fracturing has been conducted. The pressure surveys were conducted, which means that the shut-in time and depth where the pressure data observed were not sequential throughout the field. The output of the fuzzy system is categorized as: good candidate, maybe and bad candidate.

Three wells selected based on the outputs: Well I, Well II and Well III. According to the parameters considered and input data mentioned above, the first well (Well I) shows good results of re-fracturing.

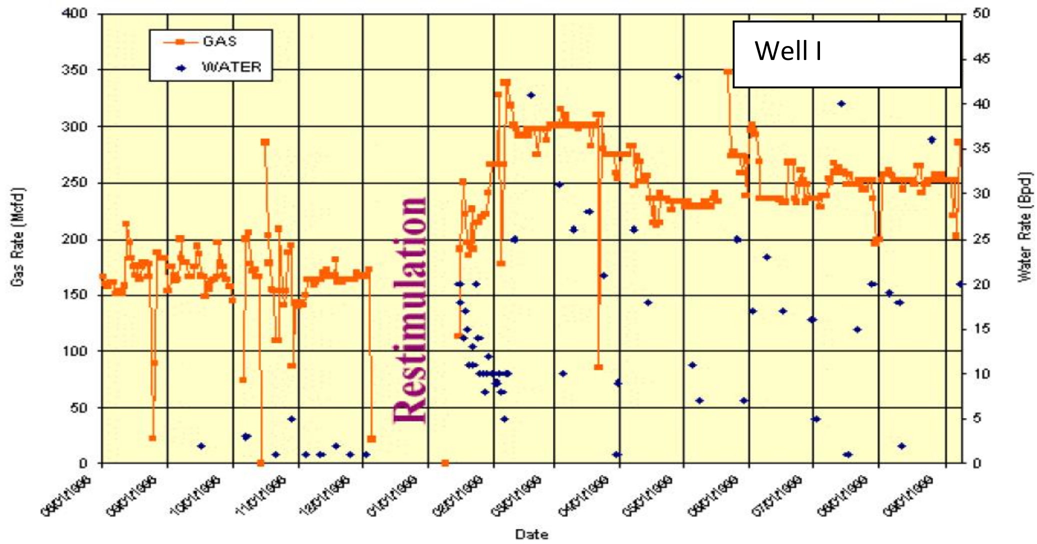

Figure 4.10: Gas and water production before and after re-fracturing for Well I (Shahab M. et al., 2000).

Well II and III did not show any improvements after re-fracturing. The results are illustrated below.

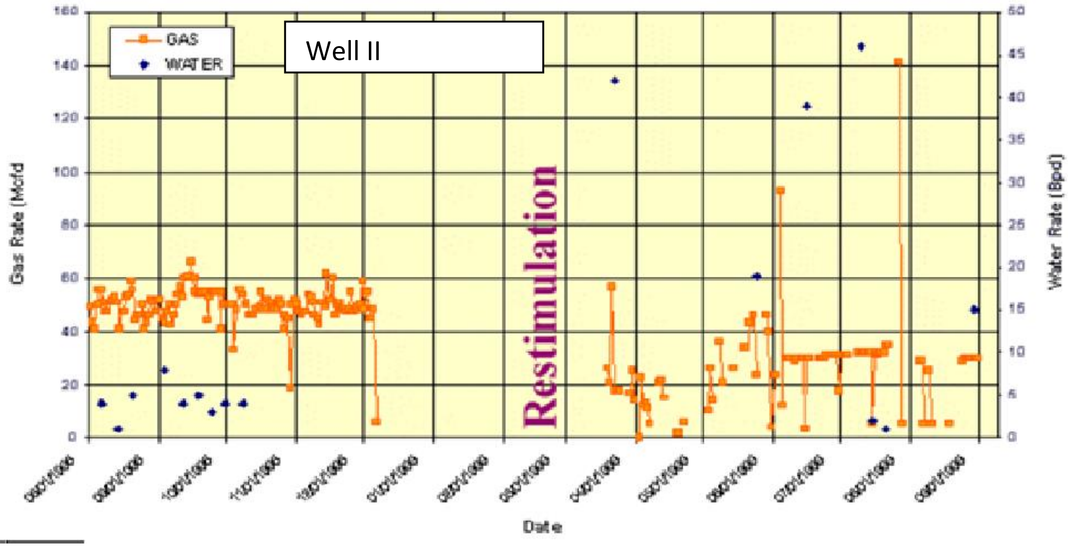

Figure 4.11: Gas and water production before and after re-fracturing for Well II (Shahab M. et al., 2000).

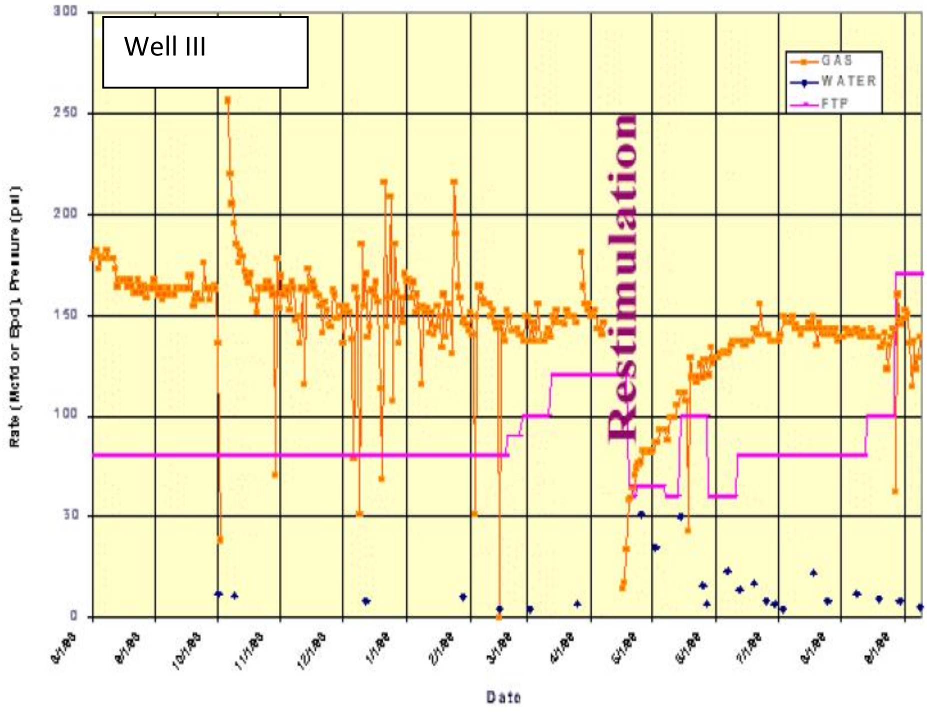

Figure 4.12: Gas and water production before and after re-fracturing for Well III (Shahab M. et al., 2000).

CHAPTER 5

CONCLUSION AND RECOMMENDATION

According to the study, it was observed that re-fracturing vertical shale wells, the production rate increased comparing to production results in initial fracturing, but did not reach the peak of the initial gas production rate. On the other hand, re-fracturing horizontal wells significantly increased the production rate 2-4 times and add potential reserves. Different parameters have different roles in selecting the candidates.

However, it was observed by the operators of different fields that re-fracturing gave disappointing results. Unfortunately, many companies classify the production, the operation procedure and other information which has faced the failure. The lack of data and other uncertainties give the real challenge during the research.

However, the main reason for the failure of the re-fracturing method is bad candidate selection of the wells. It has been observed by real life field operation results that neural network and fuzzy logic are capable of selecting candidate wells that show improvement after re-fracturing.

REFERENCES

1 “International Outlook: World Trends”, World Oil 224, no.8 (August 2003): 23-25

2 George D., et al., 2003. *Re-fracturing works*. Oilfield Review./http://www.slb.com

3 Sharon Y. W., et al., 2013. *What we learned from a study of re-fracturing in Barnett Shale: An investigation of completion/fracturing, and production of re-fractured wells.* Society of Petroleum Engineers.

4 Parrot D. I., et al., 1979. *A case history of massive hydraulic refracturing in the Tight muddy “J”*. Society of Petroleum Engineers.

5 French S., et al., 2014 *Re-fracturing horizontal shale wells: Case history of a Woodford Shale Pilot Project.* Society of Petroleum Engineers.

6 Nicolas P. R., et al., 2011. *Selecting candidate wells for refracturing using production data.* University of Texas at Austin.

7 http://halliburtonblog.com/before-abandoning-your-well-why-not-consider-a-re-frac/

8 Craig, D. and East, L., “Refracturing Technology Increases Production in Previously Fractured Single and Multiple Zone Wells Experiencing Production Declines,” *Fuel from Knowledge Central*^{TM} (September 2006).

9 Reese, J.L., Britt, L.K., and Jones, J.R., “Selecting Economic Refracturing Candidates,” *SPE* (September 1994), p. 285-290.

10 M.C. Vincent, “Restimulation of Unconventional Reservoirs: When are Re-fracs Beneficial?,” *Journal of Canadian Petroleum Technology* (August 2010), p. 36-52.

11 M.C. Vincent et.al, 2010. Refracs- Why do they work, and why do they fail in 100 published field studies?.

12 Larry K. Britt and Jerry Schoeffler, 2009. “The geomechanics of a Shale Play: What makes Shale prospective”.

13 Modeland, N., Buller, D., Chong K.K., 2011. “Stimulation’s Influence on Production in the Haynesville Shale: A playwideExamination of Fracture-treatment Variables that show effect on production”.

14 Moore, L. P., Ramakrishnan, H., 2006. ”*Restimulation: Candidate selection methodologies and treatment optimization*”.

15 Craig M., Wendte S., Buchwalter, J., 2012. “Barnett Shale Horizontal re-stimulations: A case study of 13 wells”.

16 Elbel, J.L., Mack, M.G., 1993. “Refracturing: Observations and theories”.

17 M. E. Fleming: “Successful Refracturing in the North Westbrook Unit”, Permian Basin Oil and Gas Recovery Conference, Midland, Texas, March 18-20, 1992.

18 Gordon Pospisil, et al.: “Results of a Large-Scale Refracture Stimulation Program, Kuparuk River Unit, Alaska“, Annual Technical Conference and Exhibition, Washington, DC, October 4-7, 1992.

19 K. A. Hejl.: “High-Rate Refracturing: Optimization and Performance in a COZ Flood”, Rocky Mountain Regional Meeting, Wyoming, May 18-21, 1992.

20 Wang Fengjiang, Ding Yunhong, and Lu Yong, Langfang. “A Study of Refracturing in Low Permeability Reservoirs”, Branch of Research Institute of Petroleum E. & D.,CNPC

21 Shahab M. et al., 2000 “Development of an Intelligent Systems Approach for Restimulation Candidate Selection”, West Virginia University, Scott Reeves, Advanced Resources International, David Hill, Gas Research Institute.
22 R. Jayakumar, R. Rai, A. Boulis. “A systematic study of refracturing modeling under different scenarios in shale reservoirs”. Weatherford.
23 David Strother, Rodridgo Valadares, and Amit D. Nakhwa. “Challenges of refracturing horizontal wells in unconventional wells and tight reservoirs”.