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Investigation of the effect of polymer concentration in fracturing fluid on crack size and permeability during hydraulic fracturing

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ABSTRACT

Purpose: This article aims to investigate the impact of polymer type and concentration in the fracturing fluid on the size and permeability of fractures during hydraulic fracturing. The aim is to predict the conductivity and productivity of the formed fractures in order to evaluate the cumulative gas production.

Design/methodology/approach: The influence of polymer concentration in the fracturing fluid on the size and permeability of fractures was studied using the GOHFER software from Haliburton.

Findings: The results of the study show that by combining the effect of increasing fracture size and decreasing the permeability of the proppant, a gas flow rate increase of 3.5 times was achieved.

Research limitations/implications: High polymer concentrations lead to reduced permeability due to the accumulation of polymer residues and polymer skin.

Practical implications: The conducted study on the impact of polymer concentration in the fracturing fluid on the size and permeability of fractures will allow for a more qualitative hydraulic fracturing process.

Originality/value: This article presents how the concentration and type of polymer affect the width, thickness, length, and conductivity of fractures during hydraulic fracturing.

Keywords: Well, Polymer, Concentration, Flow rate, Hydraulic fracturing

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METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

Improving hydraulic fracturing (HF) technology is becoming increasingly relevant due to the depletion of currently actively developed oil and gas deposits. Therefore, oil and gas companies are paying more attention to methods of influencing the reservoir to increase the fluid inflow to the well. The study of the HF process is an important task of our time. One of the main directions of its improvement is its combination with other methods of intensifying fluid inflow and a more detailed study of the technological parameters of the process [1,2].

Hydraulic fracturing in the deposits has been widely and effectively used in Ukraine since 1960. From 1957 to 1970, HF was carried out using gelled oil and quartz sand to fix the cracks. Later, HF was carried out using water or aqueous polymer solutions.

Since 1996, powerful hydraulic fracturing (PHF) has been used, which differs from the previous one by using highly viscous non-Newtonian fluids, fixing cracks with high concentrations of ceramic proppants, increasing fluid flow rates, and pressure injection. Since then, there has been a need to increase the justification of choosing objects for HF and using more effective technology or improving existing HF technology [3,4].

This study aims to investigate the influence of polymer concentration in hydraulic fracturing fluid on the size and permeability of fractures during hydraulic fracturing of the reservoir. Increasing the concentration of polymer leads to an increase in the viscosity of the fluid and a decrease in the absorption of the solution by the reservoir. This contributes to an increase in the value of net pressure (P_{net}), which in turn leads to the creation of larger fractures. Net pressure expresses the difference between the pressure in the fracture and the lateral rock pressure. Net pressure is a factor that directly affects the size of the fracture, and its value increases with increasing polymer concentration in the solution (at the same fluid pumping parameters). Increasing the geometric parameters of the fracture positively affects the productivity of the well after hydraulic fracturing, increasing the dimensionless conductivity of the fracture and the well productivity coefficient.

When considering the impact of increasing polymer concentration on fracture conductivity (F_c), we observe exclusively negative effects. It is because as the mass of the polymer used increases, the permeability of the proppant material deteriorates significantly, and the subsequent cleaning and removal of the polymer residue from the fracture are impaired.

In order to evaluate the impact of polymer on fracture conductivity, the main parameters under investigation are Fracture Conductivity (F_c) and Fracture Conductivity Dimensionless (F_{cd}).

Dimensionless fracture conductivity (F_{cd}) is defined as fracture conductivity divided by reservoir permeability (k) multiplied by the fracture half-length, x_f (ft) (Equation 1). It provides a means of optimising the amount of conductivity in a fracture for varying permeability and fracture length.

$$F_{cd} = \frac{k_f \cdot w}{k \cdot x_f} \tag{1}$$

were $k_f \cdot w$ – fracture conductivity, md·ft; k – reservoir permeability, md; x_f – fracture half-length, ft.

This effect significantly reduces the well productivity by decreasing the relative permeability of hydrocarbons.

However, despite all the above conclusions, they do not provide a complete answer to the influence of the polymer in actual reservoir conditions, as only 2D geometric models were considered. It is assumed that its height remains constant during crack development, and the influence of the polymer concentration on it is not considered.

Considering the positive and negative effects of the polymer on good productivity, there is a need for research on how the effectiveness of hydraulic fracturing will change when using fluids with different polymer concentrations.

It is necessary to simulate the hydraulic fracturing process using 3D models with subsequent analysis of changes in geometric parameters such as crack width, height, length, permeability, and overall hydraulic fracturing efficiency, with the calculation of the maximum well flow rate and the prediction of production.

2. Literature review

Various researchers have studied the effect of polymers on fractures during hydraulic fracturing (HF). According to their studies, the gel affects many parameters during HF. Among the main polymer effects are its ability to create filter cakes, improve proppant transport function, reduce hydraulic friction losses, and worsen proppant pack permeability. During the investigation of the geometric dimensions and productivity of the fracture, the properties of polymers were studied to change the size of the fracture due to changes in the solution viscosity, reduce fluid losses by creating a filter cake, and influence the permeability of the anchoring material [5,6].

The following fluids are used for hydraulic fracturing:

- Oil or water-based fluids, usually "crosslinked" to provide the necessary viscosity;
- Mixtures of oil and water, called emulsions;
- Foamed oil and water-based systems containing nitrogen or carbon dioxide gas.

Fluids used in early experimental hydraulic fracturing (HF) treatments were made from gasoline gelled with palm oil and crosslinked with naphthenic acid. This technology was developed during World War II and used for napalm production. Due to the hazards associated with this fluid and its relatively high cost, efforts were made to develop safer fluids with water as the base fluid.

By the late 1950s, water-based fluids with guar as the gelling agent became increasingly popular. The first treatment using crosslinked guar was conducted in 1969. Prior to this time, only about 10% of hydraulic fracturing treatments used oil-based fluids. Currently, over 65% of all HF procedures use water-based gels with guar or hydroxypropyl guar. HF using oil-based gelled fluids and acid makes up about 5% of the total.

Reduced proppant pack conductivity due to polymer residue in the fracture can be particularly problematic in medium to high permeability reservoirs.

Identified the main drawback of polymer fluids is that the portion of the fluid left in the fracture after the HF operation significantly impairs proppant pack conductivity. For more than thirty years, fracture productivity, particularly reduced proppant pack conductivity, has been the subject of research and development by Schlumberger [7-10].

One of the primary parameters in those investigations is polymer concentration after crack closure. Experiments demonstrate that when a crack is closed, the base fluid is lost in the formation or flows back into the wellbore. Polymer molecules, which are too large to penetrate through pores, remain in the propane pack and experience a four to tenfold increase in concentration depending on the final width of the crack.

Guar and HPG cause significant and practically equivalent damage at high polymer concentrations. When guar or HPG polymer is concentrated in the propane pack up to 240 pounds per 1,000 gallons, permeability decreases to 24% of the initial permeability and 14% and 13%, respectively, when polymer concentration is increased to 400 pounds per 1,000 gallons.

3. Methods and materials

The GOHFER programme from Halliburton was chosen to simulate the effect of polymer on fracture parameters during hydraulic fracturing.

The GOHFER programme is a multidisciplinary, integrated 3D fracture geomechanical simulator with all the tools necessary for conventional and unconventional well design, analysis, and optimisation.

The simulation was performed on a "Single Vertical Well" model, the data of which are based on the results of a gas well hydraulic fracturing. The model is based on an ideally vertical well with a depth of 11,600 ft.

The main parameters that describe the physical characteristics of the reservoir are presented by the curves of the distribution of the Poisson's ratio, water saturation, Young's modulus, permeability, and effective porosity (Fig. 1). The value of the Poisson's ratio in sedimentary rocks varies from 0.1 to 0.4. It depends on the mineralogical composition of the rock. The distribution curve of the Poisson's ratio is typical for dense sandstone with a range of 0.1-0.25. Hydraulic fracturing is recommended to be carried out in productive reservoirs with low permeability values compared to the permeability of adjacent wells and in the presence of lithological screens that separate the reservoir from water-saturated collectors. Therefore, the reservoir in the perforation interval of 11370-11430 ft was chosen for further research.

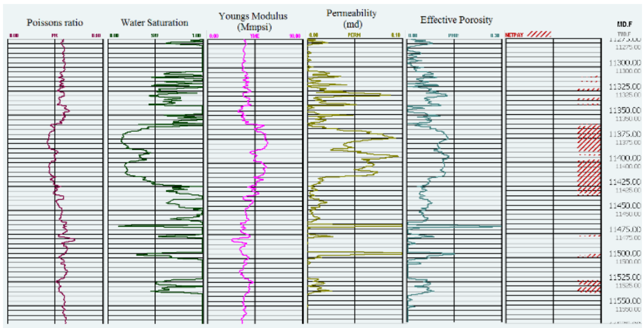

Fig. 1. Distribution curves of reservoir physical properties

In order to evaluate the effect of polymer on fracture parameters during hydraulic fracturing, it is necessary to select fracturing fluids with different polymer concentrations. It is crucial that the chosen fluids have the same type of polymer, the same composition of other additives, and a low concentration of breaker or its complete absence.

For the investigation of the effect of polymer concentration on fracture parameters, the following fracturing fluids were selected (Tab. 1).

The liquid injected at the beginning of the hydraulic fracturing process is called the "pad" and does not contain any propane. The role of this liquid is to create the fracture and ensure the subsequent successful settling of the propane. After the injection of the pad, the concentration of the crosslinker in the mixture increases sharply, and the slurry is injected to anchor the fracture.

The main parameters of hydraulic fracturing are as follows:

- The total amount of injected liquid is 31,836 gallons (120 m^3);

Table 1.
Characteristics of fracturing fluids

Fluid	Polymer type	Polymer concentration, ft/Mgal	Stitching agent	Destructor	Destructor concentration, ft/Mgal	Residual permeability, %
1						
Guar_10#_150_NA	Linear Guar	10	-	-	-	~ 60*
Guar_20#_150_NA		20				~ 60*
Guar_30#_150_NA		30				~ 60*
Guar_40#_150_NA		40				~ 60*
2						
PrimeFRAC30_300_J490_5	Guar	30	Zr (*Zirconium*)	J490	5	54
PrimeFRAC35_300_J490_5		35				52
3						
YF830_190_SP_1	Guar	30	Bor	SP	1	50
YF135_200_SP_1		35				54
YF140_180_SP_1		40				48
4						
SpecFracG_30#_215_HPCRB_1	HPG	30	Bor	PCRB	1	62
SpecFracG_35#_215_HPCRB_1		35				58
5						
Vistar_18#_200_GBW23L_2	CMG	18	Zr	GBW23L	2	64
Vistar_20#_190_GBW23L_2		20				62

* – Some data values for the fluids are missing

- Average rate of injected liquid is 27.2536 barrels per minute (0.0722 m^3/s);
- Total mass of propane used is 82,267.45 pounds (37,315 t);
- Propane concentration range in the slurry varies from 0 to 5.8 pounds per gallon (694.956 kg/m^3);
- The total duration of the hydraulic fracturing process is 1 hour, 26 minutes, and 39 seconds.
- Propane used is UNIFRAC Jordan 20/40 (A).

4. Result and discussions

Using selected hydraulic fracturing fluids, 13 simulations were conducted, divided into 5 groups depending on the type of polymer included in the corresponding fluids (Tab. 1). The polymer concentration in each group varied in different ranges and ranged from 2 to 30 feet per thousand gallons.

After conducting hydraulic fracturing modelling, the geometric parameters of the fracture were obtained, such as width, height, and length, which were given for two types of fluids, PrimeFRAC30_300_J490_5 – Figure 2a and PrimeFRAC35_300_J490_5 – Figure 2b. Similar results for the geometric parameters of the fracture for other types of fluids are shown in Table 2. Table 2 also summarises the results of the hydraulic fracturing modelling process for all selected fluids.

a) b)

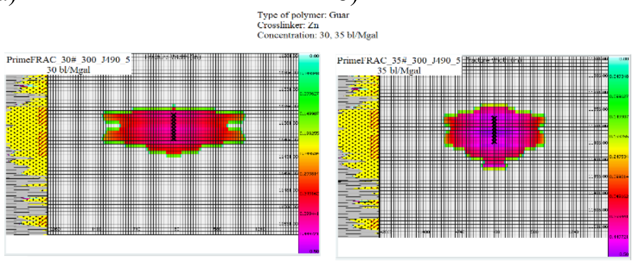

Fig. 2. Images of the fracture height, width, and length

According to Table 2, the fracture height varies from 50 feet for the Guar_10#_150_NA fracturing fluid to 100 feet for the Vistar_20#_190 GBW23L_2 fluid, respectively. It is worth noting that for the latter fracturing fluid, the maximum width of the fracture is the largest of all the studied fluids and is 0.494 inches. When comparing fracturing fluids based on the efficiency parameter, this parameter is maximum, 73.73%, for PrimeFRAC35_300 J490_5. After all simulations have been carried out, in the Engine Output Viewer tab, you can track the process of changing the main parameters of a crack during its occurrence (Fig. 3, 4).

The GOHFER software uses different fracture lengths to describe the results, including Gross Length and Flowing Frac Length.

Table 2.
Summarised results of the hydraulic fracture modelling for all the proposed fluid types

Fluid Name	Polymer concentration, lb/Mgal	Gross length*, ft	Flowing frac length**, ft	Fracture height, ft	Average fracture width, in	Maximum fracture width, in	Fracture wall area, t^2	Fracturing fluid efficiency, %	Total fluid loss, gal	Maximum net pressure, psi
					1					
Guar_10#_150_NA	10	1660	56	50	0.195522	0.275	11200	53.414	21689	1182
Guar_20#_150_NA	20	1720	58	55	0.23066	0.31	12741	60.3123	18467	1327
Guar_30#_150_NA	30	1700	57.9	60	0.271817	0.352	13896	68.4055	14705	1507
Guar_40#_150_NA	40	1560	57.3	70	0.315036	0.399	16045	73.5	12335	1683
					2					
PrimeFRAC30_300_J490_5	30	1180	57.8	80	0.3462	0.426	18498	68.805	14526	1784
PrimeFRAC35_300_J490_5	35	920	54.3	100	0.3956	0.494	21722	73.73	12227	2033
					3					
SpecFracG_30#_215_HPCRB_1	30	1460	58.3	80	0.3054	0.412	18664	66.25	15699	1733
SpecFracG_35#_215_HPCRB_1	35	1280	57.4	80	0.3293	0.435	18370	67.5024	15108	1815
					4					
YF830_190_SP_1	30	1140	60.7	65	0.314265	0.401	15778	62.1	17630	1693
YF135_200_SP_1	35	1100	60	70	0.322189	0.412	16466	63	17203	1835
YF140_180_SP_1	40	1100	60	70	0.327451	0.417	16614	63.5	16990	1949
					5					
Vistar_18#_200_GBW23L_2	18	1040	57.4	80	0.366358	0.453	18365	68.08	14851	1915
Vistar_20#_190_GBW23L_2	20	900	54.5	100	0.393221	0.494	21800	70.68	13638	2032

* Gross Length (A) – The fracture length where rock breakage has occurred. This is essentially the maximum length of the fracture, including portions not filled with proppant.
** Flowing Frac Length (D) – It is the length of the fracture where a steady flow of fluid is guaranteed.

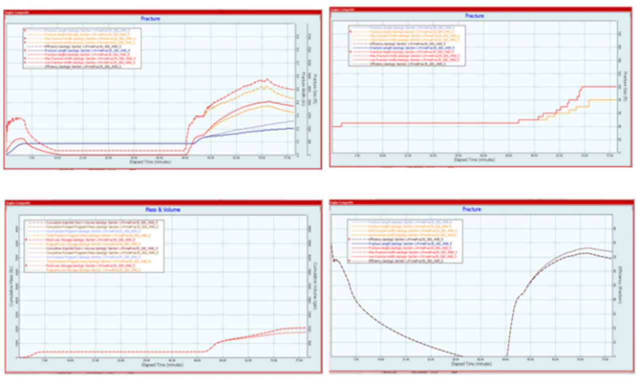

Fig. 3. Variation of key fracture parameters during HF Fluid: PrimeFRAC Polymer type: Guar + Zr

As is well known, the effectiveness of a fracturing fluid η_e is defined as the ratio of the volume of fluid remaining in the fracture to the total volume of injected fluid (Equation 2)

$$\eta_e = \frac{V_f}{V_i} \qquad (2)$$

were V_f – volume of fluid remaining in the fracture, m^3; V_i – volume of injected fluid, m^3.

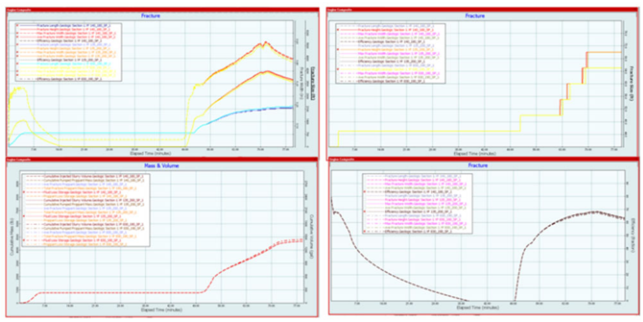

Fig. 4. Changes in the main fracture parameters during HF. Fluid: YF Polymer Type: Guar + Br

Increasing the portion of the fracturing fluid that remains in the fracture leads to an increase in the internal net pressure. Increasing the polymer concentration in all the fluids used for modelling resulted in an increase in the width and height of the fracture, but the length of the fracture decreased (Tab. 2). Fluid loss and fluid viscosity play a crucial role in line with the previous studies. Increasing the polymer concentration contributes to the formation of thicker and less permeable filter cakes, reducing fluid loss.

The less fluid the formation absorbed, the more of it remains in the fracture, and the net pressure creates wider and higher fractures. The fracture wall area parameter was used to simultaneously assess the increase in fracture height and decrease in fracture length, which also increases with polymer concentration.

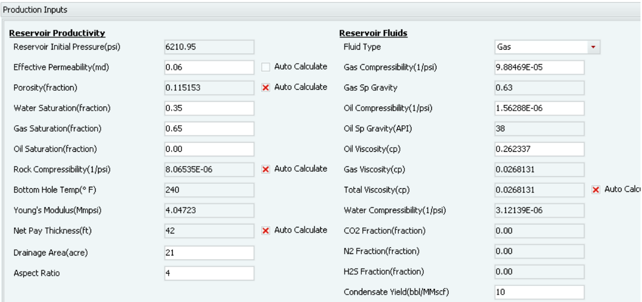

Fig. 5. Data on the created fracture and productive formation (for the Guar 10 fluid model)

After all the modelling was completed, the Production analysis function was used to forecast the conductivity and productivity of the created fractures. The production forecast was performed for a duration of 131 days. The forecast made it possible to calculate the cumulative gas production for each case. The input data for creating the forecast are shown in Figure 5.

Assuming that the average width of the fracture (from Tab. 2) is equal to the average thickness of the proppant-filled fracture, the permeability of the proppant pack can be calculated using Formula 2. The results of the calculations are presented in Tables 3, 4.

In all types of polymers, increasing their concentration negatively affects the permeability of proppant in the fracture. It is due to the damage caused to the fracture by residual gel, which is taken into account during modelling using the GOHFER program.

Table 4.
Proppant pack permeability

Fluid Name	Proppant pack permeability, md
Guar_10#_150_NA	24.92
Guar_20#_150_NA	22.83
Guar_30#_150_NA	21.97
Guar_40#_150_NA	19.61
PrimeFRAC30_300_J490_5	27.94
PrimeFRAC35_300_J490_5	22.89
SpecFracG_30#_215_HPCRB_1	32.46
SpecFracG_35#_215_HPCRB_1	26.66
YF830_190_SP_1	37.93
YF135_200_SP_1	35.69
YF140_180_SP_1	35.96
Vistar_18#_200_GBW23L_2	32.23
Vistar_20#_190_GBW23L_2	29.16

Table 3.
Productivity analysis results

Fluid Name	Polymer concentration, lb/Mgal	FCD	Fracture conductivity, md·ft	Maximum gas rate, Mscf/day	Accumulated gas production, MMscf
		1			
Guar_10#_150_NA	10	0.348623	0.406087	1086	119.427
Guar_20#_150_NA	20	0.373504	0.438837	1233	101.678
Guar_30#_150_NA	30	0.397213	0.4978	1373	92.46
Guar_40#_150_NA	40	0.405899	0.51502	1623	81.93
		2			
PrimeFRAC30_300_J490_5	30	0.539847	0.806144	1905	134.5
PrimeFRAC35_300_J490_5	35	0.517807	0.754891	1773	131
		3			
SpecFracG_30#_215_HPCRB_1	30	0.558936	0.826363	1919	135.672
SpecFracG_35#_215_HPCRB_1	35	0.517481	0.73183	1863	132.784
		4			
YF830_190_SP_1	30	0.628065	0.993545	1722	120
YF135_200_SP_1	35	0.613961	0.958484	1861	129.853
YF140_180_SP_1	40	0.62324	0.981497	1870	130.152
		5			
Vistar_18#_200_GBW23L_2	18	0.6126	0.984274	1990	137.784
Vistar_20#_190_GBW23L_2	20	0.601265	0.955631	1973	136.607
		No treatment well			
No treatment well	0	0.028279	0.007846	421	34.3754

To further compare the efficiency of hydraulic fracturing and gas flow rate after treatment, it is necessary to model a well with a minimum possible fracture (Fig. 6), which was formed due to a very small amount of slurry injection.

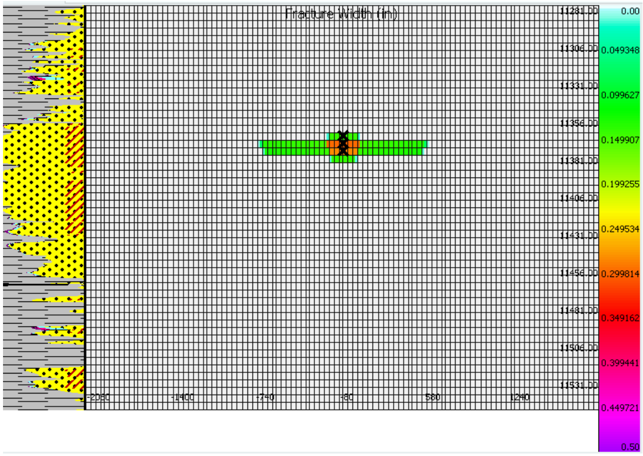

Fig. 6. Width of hydraulic fracture without the use of polymer in the fracturing fluid

We will consider this well as a well on which hydraulic fracturing of the formation was performed without the use of polymer in the fracturing fluid.

Input data for modelling of the hydraulic fracturing without using polymer in the fracturing fluid are as follows (the amount of fluid and propane was chosen as minimal for the possibility of conducting productivity analysis):

- Total volume of injected fluid: 9000 gal;
- Total amount of propane used: 8000 lbs;
- Propane concentration: 1 lb/gal;
- Working fluid type: SilickWater_150F;
- Polymer concentration: 0 lbs/Mgal;
- Proppant name: UNIFRAC Jordan 20/40 (A).

Such information is essential in hydraulic fracturing design and optimisation. The concentration of proppant and working fluid, as well as the type of proppant, have a significant impact on the effectiveness of the hydraulic fracturing process. Therefore, accurate and detailed data acquisition is critical to ensure optimal production from the reservoir.

Taking the maximum gas flow rate as "1", the multiple increase in gas flow rate was calculated after hydraulic fracturing for the modelling purpose.

Comparison of changes in the maximum gas flow rate and the accumulated gas production over time for the case of using PrimeFRAC fluid is shown in Figures 7 and 8.

To generalise the effect of polymer, a well-productivity analysis was conducted for a period of 131 days. The results showed that combining the effect of increased fracture size and decreased proppant permeability, different dependencies of gas rate and cumulative production on polymer concentration were obtained for different fluids. Simulation results indicated that the polymer has a uniform influence on fracture parameters for the investigated fracturing fluids, namely, an increase in fracture size and deterioration in proppant conductivity. However, the degree of polymer action depends on its chemical and physical properties.

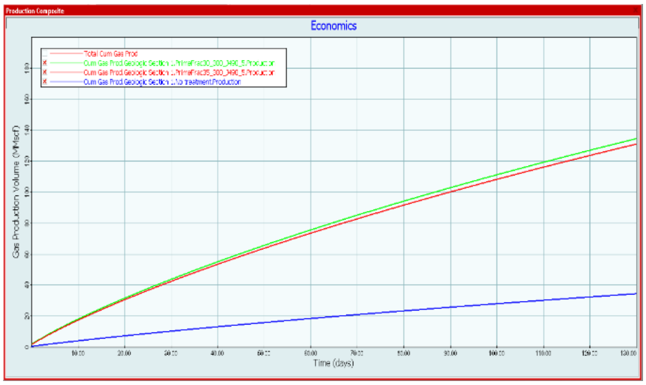

Fig. 7. Gas flow rate changes over 131 days (PrimeFRAC)

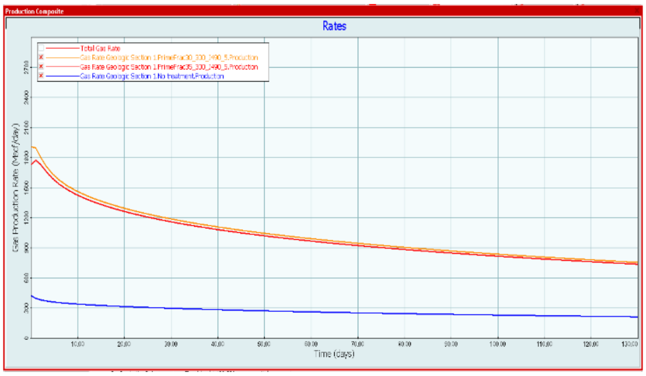

Fig. 8. Comparison of cumulative gas production (PrimeFRAC fluid) with cumulative gas production without HF reservoir

5. Conclusions

The influence of polymer concentration in the working fluid on the size and conductivity of fractures during hydraulic fracturing was investigated. For all types of fluids used in the simulation, an increase in polymer concentration increased the basic geometric parameters, such as fracture width and height, and a decrease in its length.

Analysis of the polymer's influence on conductivity revealed a decrease in propane permeability with increased polymer mass used during fracturing. The deterioration in permeability was caused by polymer residues and the polymer cake, which increased in thickness with increasing polymer concentration, reducing permeability and mobility.

In the case of linear guar and YF fluid (Guar + Bor), an increase in gas rate and cumulative gas production with increasing polymer concentration was observed. However, for Prime FRAC fluid (Guar + Zr), SpecFracG (HGP + Bor), and Vistar (CMG + Zr), opposite results occur. Increasing the polymer concentration sharply reduces the conductivity of the fracture, and as a result, fractures with larger widths had lower productivity.

For a more comprehensive study of the polymer's effect, it is necessary to combine hydraulic fracturing simulation in the program with laboratory experiments on the effect of polymer on rock samples. Those results should be combined with studies of the rheological, filtration, and proppant transport properties of the fluid samples for hydraulic fracturing with a wider range of polymer concentrations.

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