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INTEGRATED MODEL OF HYDRAULIC FRACTURING AND HYDROCARBON PRODUCTION

1. NOMENCLATURE

CALIPER	Caliper (m)
GR	Gamma Ray (API)
PERM	Permeability – Perm/Perm$_{max}$ (fraction)
PHIE	Effective porosity (fraction)
PORE_P	Pore pressure (Pa)
PR	Poisson's Ratio (fraction)
PZS	Process Stress Zone (Pa)
RESIST	Resistivity (ohm·m)
RHOB	Bulk density (kg/m^3)
STRESS TOTAL	Stress total (Pa)
VCOAL	Coal fraction (fraction)
VDOLO	Dolomite fraction (fraction)
VLIME	Lime fraction (fraction)
VNAHD	Anhydrite fraction (fraction)
VSAND	Sand fraction (fraction)
VSHALE	Shale fraction (fraction)
YMES	Static Young's modulus (Pa)

2. INTRODUCTION

Owing to the heterogenity of reservoir layers, the shape of the fracture can be properly predicted only on the basis of a properly selected fracture model and quality of

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geological-reservoir properties. The complexity of this process causes that the analysis of expected results cannot be done quickly. In this case complex numerical modeling of this operation is very useful as it accounts for geomechanical properties of rocks, varying distribution of stresses, gradient of geostatic and reservoir pressure as well as filtration parameters connected with exploitation model of the reservoir (Wojnarowski and Stopa, 2012).

Initially the fracturing simulators were based on 2D models, however with the developing technology and its use in complex geological conditions the required accuracy of fracturing increased due to, among others, the sensitivity of economic results to the expected hydraulic fracturing results. The 3D or pseudo 3D (p3D) models became more popular (Wojnarowski, 2012). However, the use of more advanced models is limited by the availability and quality of geological-reservoir data, therefore in a number of cases the 2D models are still applicable for obtaining satisfactory approximation of actual geometry of the fracture with the use of basic data (Economides et al., 2002). In the case of tight or shale gas reservoirs the 3D models have to be involved, as by accounting for the geomechanical properties of neighboring strata and heterogenity of the reservoir, they give a more realistic picture of facture propagation (Barree, 2009). Advanced models are based on stress balance, energy balance, fluid flow and transport of the proppant, as well as equation of fracturing fluid filtration to the rock matrix. In 3D models the fracture sizes do not depend on one another. They enable modeling of an irregular set of fractures, the shape of which is conditioned by local properties of reservoir. With the obtained modeling results the efficiency of the procedure can be evaluated applying simple analytical solutions or reservoir simulations, performed as an individual calculation process based only on the fracturing results. This solution is limited by the lack of full integration of the project with the predicted production, which is necessary for optimization processes (Stopa, 2012). Fracturing modeling together with production simulations can be used for iterative correcting of the project, finally leading to its optimization. The schematic of the optimization model is given in figure 1.

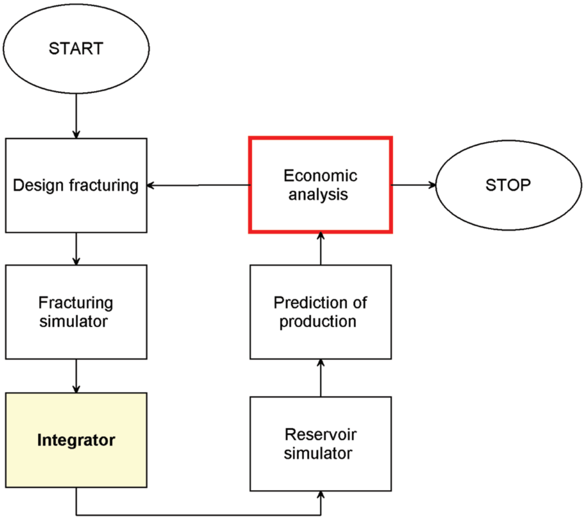

Fig. 1. Schematic of iterative optimization of hydraulic fracturing treatment

The first step to obtaining the optimization model of fracturing process is integration of treatment design and simulation of production.

3. INTEGRATION OF FRACTURE MODEL WITH RESERVOIR SIMULATOR

An example of software based on a three-dimensional fracture propagation model is GOHFER (Baree & Associates, 2012). This is a composite tool to be used at the stage of designing and the preliminary analysis of the hydraulic fracturing efficiency. The advantage of this program is the use of well geophysical log surveys in the form of LAS files, enabling detailed projection of varying properties of the rock in the model. The applied method is based on discretization of the rock with a grid of regular blocks, analogous as in the case of reservoir simulators (Wojnarowski and Stopa, 2012). The calculations of parameters of the obtained fracture are made in each block of the grid, in successive time-steps, accordingly to treatment schedule. Thus obtained fracture geometry accounts for locally changing properties of the reservoir layer. The program is also equipped with a module for production predicting, based on the analytical equation of well influx. This hinders the evaluation of efficiency of operation in reservoirs having complex build. Moreover, the program does not have any module which would export simulation results to the reservoir simulator. This causes that the results cannot be directly used for evaluating the process efficiency, and assessing fracture's impact on the production, not only in the well area but also over the entire reservoir.

Author's 'Frac Export' software enables one to integrate the hydraulic fracturing results with the reservoir simulator. The proposed software plays the role of an 'integrator' providing a quick exchange of data between the fracturing simulator and the reservoir simulator. The program was written in language C++. It cooperates with GOFHER software and the ECLIPSE package by Schlumberger. The block diagram of the program operation is presented in figure 2.

The program requires files coming from GOHFER software, as they contain basic pieces of information about the calculation grid, its size and location in the depth profile, and placement of perforations. Geometrical data are coupled with the results of predicted treatment results (fracture geometry, proppant concentration, its type and properties in a function of stress). On the basis of proppant concentration distribution in the fracture and its properties, the permeability distribution in the area subjected to fracturing is defined. Then the fracture property matrices are transformed to a numerical grid of the reservoir simulator. The program automatically checks out if the grid containing the fracture stays within the reservoir simulator grid. As a result we get a code specifying local grid refinement of reservoir grid with the introduced fracture properties and gradual change of blocks size, adjusted to the size of blocks in the reservoir model. Thus obtained fracture is represented by an area with improved filtration properties. Its size is determined by the range of hydraulic fracturing range. The obtained results create an integral part of the input code for the reservoir simulator.

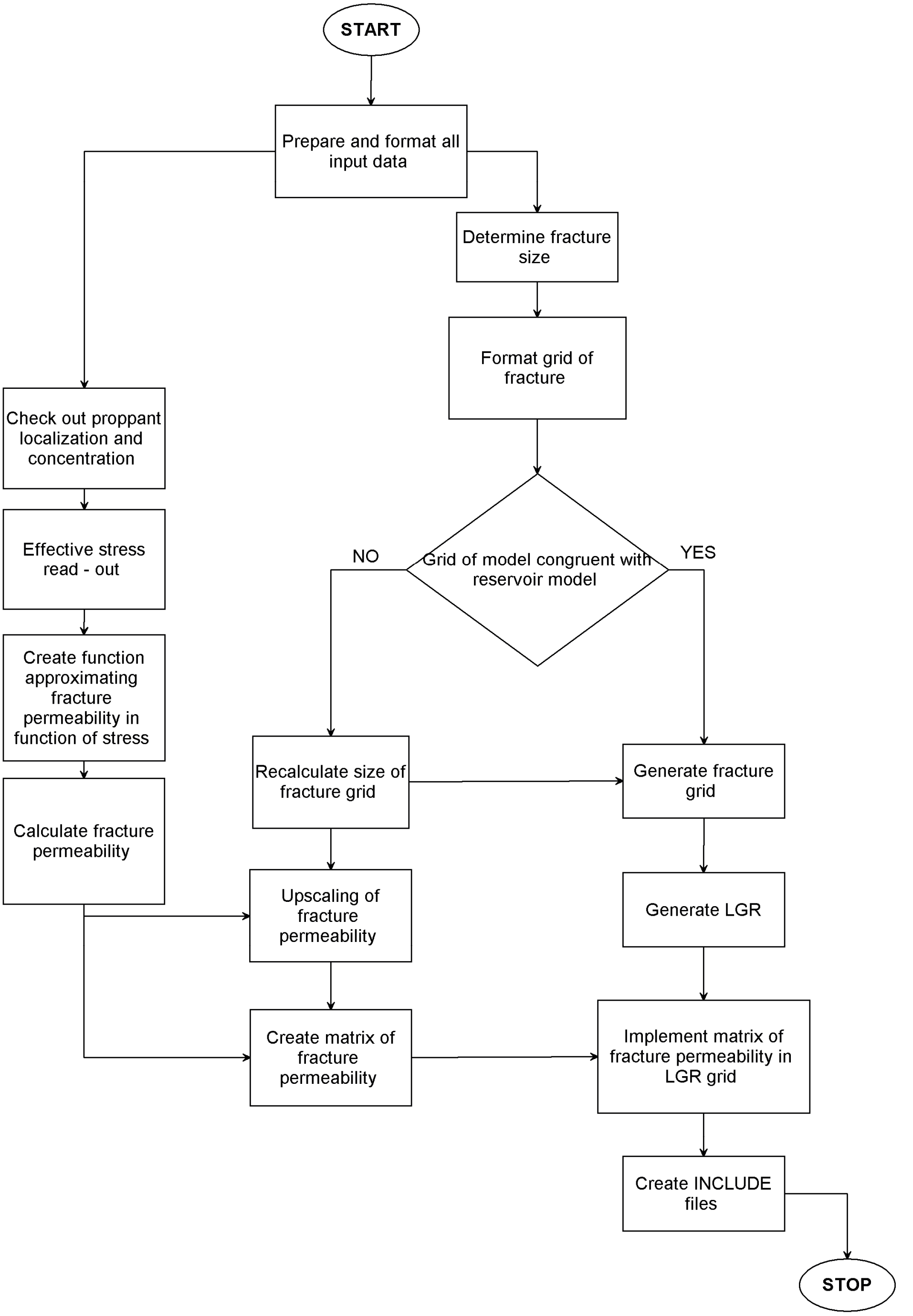

Fig. 2. Block diagram of a module combining fracturing simulator and reservoir simulator

4. APPLICATION OF INTEGRATED HYDRAULIC FRACTURING AND EXPLOITATION SIMULATION

For the presented coupling of hydraulic fracturing simulation with reservoir simulation demonstration, there were used data from Williams PA-424-34 well, opening out a ‘tight gas’ reservoir in Piceance Basin in USA (Available at: http://discovery-group.com/projects_doe_piceance.htm). Well logs were used for construing a geomechanical model for designing hydraulic fracturing with the use of GOHFER software. The processed basic well-log data used in the simulation are presented in figure 3, and the main reservoir properties, later used in this paper, are listed in table 1.

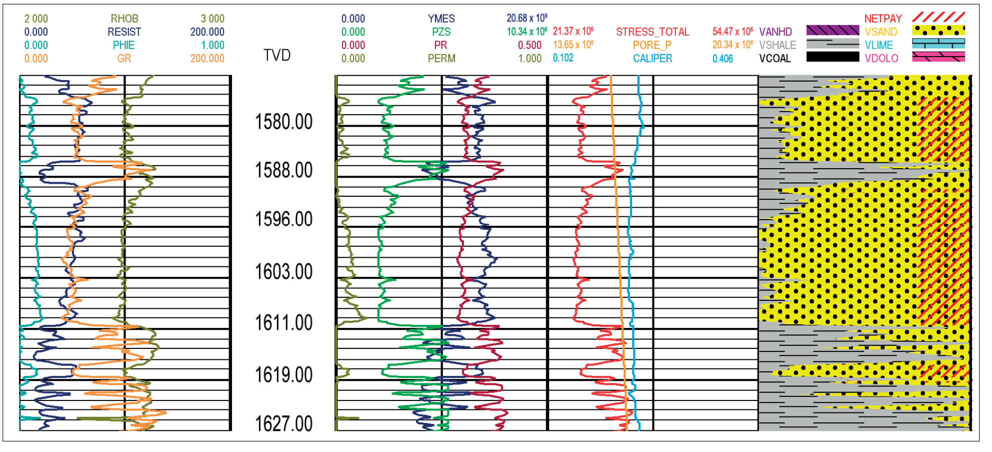

Fig. 3. Input well logs and determined reservoir parameters

It was assumed that 191 m^3 of fracturing fluid and about 53 tones of proppant would be used in the hydraulic fracturing model. The selected proppant was of 20/40 mesh. The polymer concentration in fracturing fluid was assumed to be of 4.8 kg/m^3 (40lb/1000gal).

The hydraulic fracturing simulation resulted in a fracture with the range of both wings equal to 1200 [m], average width 7.6 [mm] and maximum height 25.9 [m]. The average proppant concentration in the formed fracture was 1.953 [kg/m^2]. The ultimate geometry of fracture and proppant concentration are presented in figures 4 and 5, respectively. The proppant range shows supported part of the fracture and in the analyzed case equals to about 450 meters of length for the individual fracture wing.

Using the results of fracturing simulator and the ‘integrator’, a fracture permeability matrix was determined. It consisted of 290 columns and 21 rows, representing a zone of filtration improved by fracturing operation.

The reservoir data were used for making a simplified simulation model of the near-borehole zone for the ECLIPSE simulator in the form of a regular grid 50 x 50 x 7 into which the fracture would be introduced with the 'integrator' at the next stage of works. The top of the model was 1569 m b.s.l. of depth. The layers distinguished in the model are characterized in table 1.

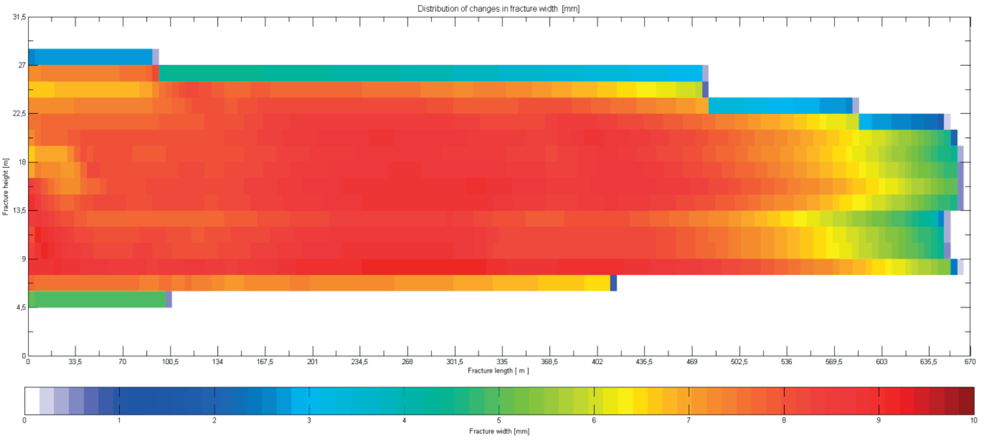

Fig. 4. Distribution of changes in fracture width (mm)

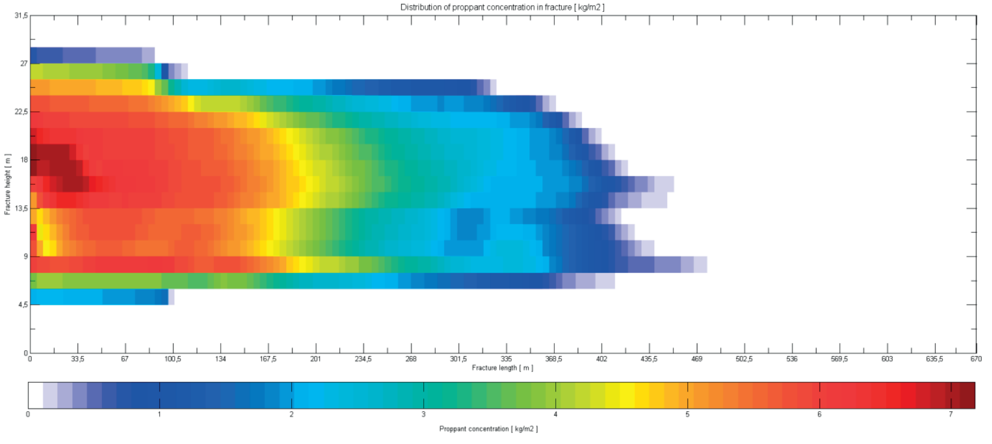

Fig. 5. Distribution of proppant concentration in fracture (kg/m^2)

Table 1

Basic properties of simulation model of near-borehole zone

Layer	Description	Thickness [m]	Porosity [%]	Perm X [mD]	Perm Y [mD]	Perm Z [mD]	S_w [%]
1	Sandstone	10	3	0.02	0.02	0.002	60
2	Shales	5	0.1	0.2E-4	0.2E-4	0.2E-5	90
3	Sandstone	12	7	0.04	0.04	0.004	3
4	Sandstone	12	9	0.07	0.07	0.007	3
5	Sandstone	12	11	0.06	0.06	0.006	3
6	Shales	5	0.12	0.6E-5	0.6E-5	0.6E-6	90
7	Sandstone	10	0.3	0.1	0.1	0.01	70

After implementing the results of hydraulic fracturing simulation to the near-borehole zone model with the ‚Frac Export' software, there appeared a local grid refinement of the simulation grid consisting of 297x5x28 blocks, thus covering the blocks of the main grid within the following ranges: 10–42 towards the fracture propagation, 24–24 perpendicular to propagation, and 3–6 in vertical direction. In the central part of local grid refinement (fracturing range) there was introduced a matrix of fractured zone permeability as presented in figure 6.

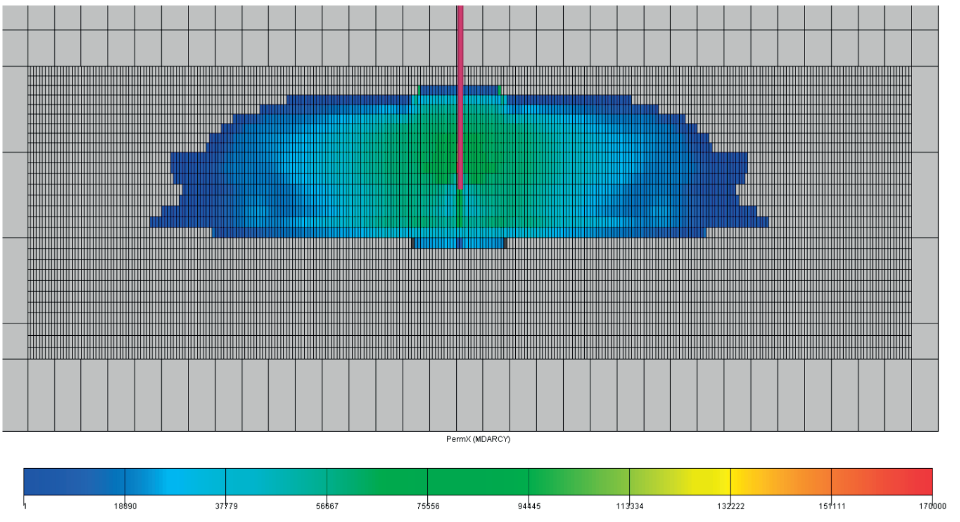

Fig. 6. Distribution of permeability in fracture implemented to reservoir simulation model

With thus prepared digital simulation model one may calculate the expected natural gas production. The distribution of pressure in the reservoir after 4 years of exploitation is given in figure 7, whereas output changes and cumulated gas production in figure 8.

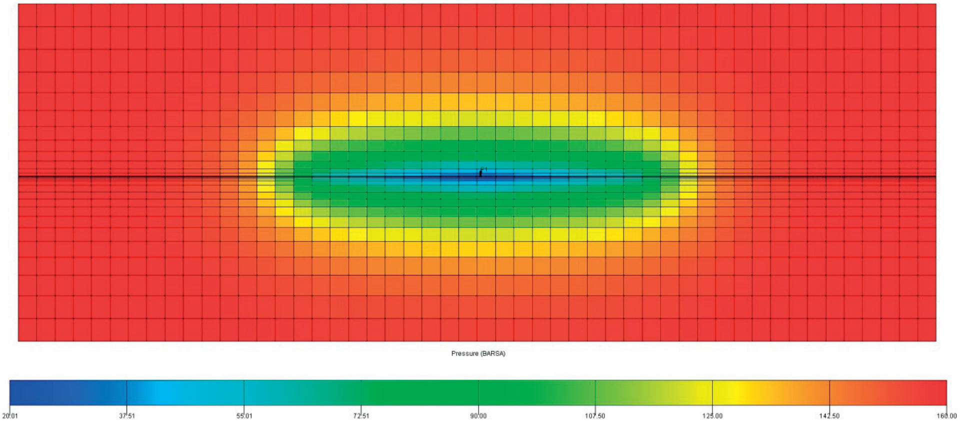

Fig. 7. Distribution of pressure in reservoir after 4 years' exploitation with a well after hydraulic fracturing

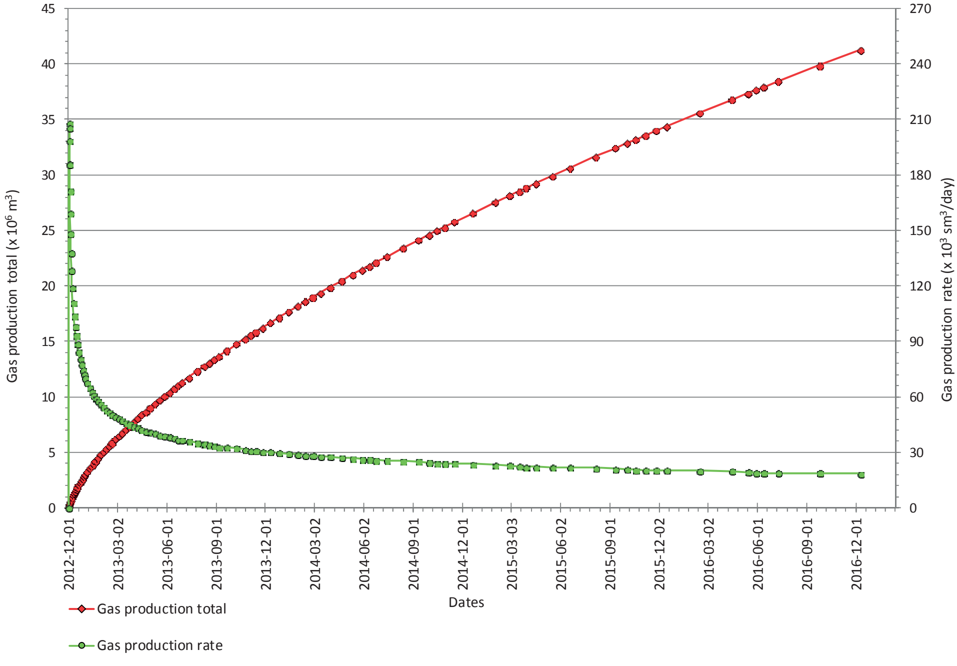

Fig. 8. Gas production from well

Thus obtained model is a fully functional tool for production modeling, based on detailed geological-reservoir data. In the need of variant simulations accounting for various hydraulic fracturing configurations, the interface integrating the treatment simulation with the reservoir simulation allows for a quick comparison of the results and optimum variant selection.

5. CONCLUSIONS

The reservoir simulation is an efficient tool for evaluation of hydraulic fracturing efficiency, providing a wide range of analyses. However, it requires a series of calculations for various configurations of the planned operation. The presented tool, i.e. 'Frac Export' enables coupling hydraulic fracturing with a full reservoir simulation, leading to a quick variant analysis of process efficiency. The 'integrator' enables one to analyze how the efficiency is influenced by the fracturing technology, on which the shape of the fracture and its filtration properties depend. The time needed for preparing alternative simulation models can be shortened thanks to the fracture projection against the reservoir. The proposed software is the first element when building an automatic iterative process of hydraulic fracturing optimization.

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