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Numerical Modelling of Crack Initiation around a Wellbore Due to Explosion

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Abstract**—**A wellbore is a hole that is drilled to aid in the exploration and recovery of natural resources including oil and gas. Occasionally, in order to increase productivity index and porosity of the wellbore and reservoir, the well stimulation methods have been used. Hydraulic fracturing is one of these methods. Moreover, several explosions at the end of the well can stimulate the reservoir and create fractures around it. In this study, crack initiation in rock around the wellbore has been numerically modeled due to explosion. One, two, three, and four pairs of explosion have been set at the end of the wellbore on its wall. After each stage of the explosion, results have been presented and discussed. Results show that this method can initiate and probably propagate several fractures around the wellbore.

Keywords**—**Crack initiation, explosion, finite difference modelling, well productivity.

I. INTRODUCTION

EXPLOSIVE stimulation by blast-fracturing was first used in well stimulation in USA before the hydraulic fracturing. The advent of hydraulic fracturing caused explosive stimulation of oil wells to decline. The hydraulic fracturing process consumes a huge amount of water and imposes a threat to the ground water resources, so it is highly desirable to revisit the feasibility of replacing hydraulic fracturing with blast-fracturing in the oil and gas well completion processes [1]. Reference [2] investigated implementation of method of explosively fracturing as a productive oil/gas method. In [3], it has been claimed that in reservoirs where unconnected streaks exist, the application of hydraulic fracturing may not be effective. They further presented various explosives available for application. Reference [4] presented several results from field application of explosive fracturing in oil fields in Texas, New Mexico and Oklahoma. Furthermore, a mathematical analysis for explosive fracturing in the oil and gas well has been already performed [5]. Previously, application of the explosively fracturing in oil/gas reservoirs has been studied and compared with the other stimulation methods [6], [7]. Moreover, initiation and propagation of blast-induced radial cracks around the wellbore have been investigated [1], [8], [9].

Fracture mechanics has been proposed as a possible tool for solving a range of rock engineering problems, such as explosive fracturing, rock cutting, hydrofracturing, rock stability, etc. [10]. Furthermore, Linear Elastic Fracture Mechanics (LEFM) principles have been widely used in rock fracture mechanics [11]-[13]. Mechanical behaviors of rocks affected by high explosion loads are difficult and costly to be studied exclusively by instrumentation and experimental works. In addition, the explosion induced fractures in rock propagate very quickly. Therefore, rock dynamic fracture mechanisms can be studied by the sophisticated numerical methods [14], [15]. The effects of free face, in-situ stresses and load density on the rock fracturing process have been investigated in order to study crack initiation and propagation due to blasting [16]-[20]. In the use of fracture mechanics for crack propagation in hydrocarbon reservoirs, propagation of one or more hydraulic fractures from a wellbore was studied using displacement discontinuity method [21].

In order to investigate explosive fracturing in the wellbore in this study, crack initiation induced by blasting in rock is generally considered and modeled numerically using Finite Difference Method (FDM). Therefore, four different set of explosives in the wellbore were considered: 1) one, 2) two 3) three and 4) four pairs of explosion have been set at the end of the wellbore on its wall. The explosives was exploded in these models and patterns of the induced cracks around the wellbore were investigated and discussed.

II. DYNAMIC FINITE DIFFERENCE MODELLING

As previously mentioned, in this study four different patterns of explosives are set in a wellbore and dynamic simulation of the explosion was performed numerically on them using Fast Lagrangian Analysis of Continua (FLAC) software. FLAC has a time-marching explicit finite difference algorithm for solving dynamic problems such as rock blasting [22]. Fig. 1 shows geometry of the considered models. In here, radius of the wellbore is assumed to be 0.1 m. The proposed number of the separate explosive charges in here is based on previous studies about number of created cracks around a blast hole [10], [23].

As shown in Fig. 1, the explosion process was simulated in separate spherical charges around the wellbore. The spacing between the explosive charges are 180° in Fig. 1 (a), 90° in Fig. 1 (b), 60° in Fig. 1 (c), and 45° in Fig. 1 (d). In this study, it is assumed that all of the explosive charges are exploded simultaneously in the numerical modelling. Moreover, Mohr-Coulomb constitutive model is assumed as mechanical behavior of the rock and geomechanical properties of the considered rock models are tabulated in Table I.

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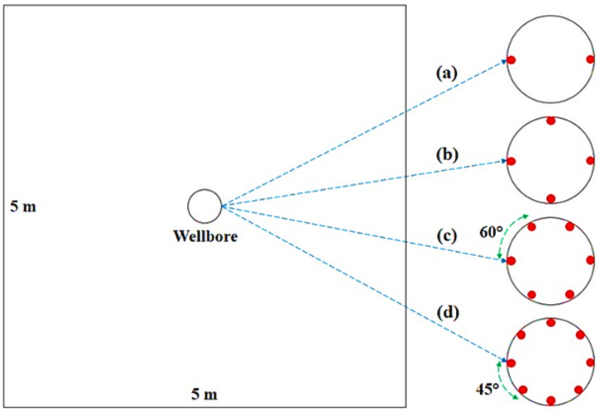

Fig. 1 Geometry of the considered models with (a) two, (b) four, (c) six and (d) eight separate spherical explosive charges

TABLE I
GEOMECHANICAL PROPERTIES OF THE CONSIDERED OIL SHALE

Quantity	Value	Unit
Density	2600	(kg/m^3)
Yung modulus	7.5	GPa
Poisson ratio	0.3	-
Cohesion	12	MPa
Fraction angle	40	°
Tensile strength	3	MPa

Dynamic analysis is often very complicated and requires a considerable amount of insight to be interpreted correctly. The most important stage in dynamic problems is dynamic input into the system [24]. In order to calculate the explosion pressure as a function of time, a set of formulations can be used. The detonation pressure of an explosive can be estimated from the following equation as a function of explosive density and velocity of detonation:

$$PD = 432\times 10^{-6}\times \rho_e \times \frac{VD^2}{1+\left(0.8\rho_e\right)} \tag{1}$$

where PD is the pressure of detonation in MPa, ρ_e is the explosive density in g/cm^3, and VD is the velocity of detonation in m/s [25]. In practical purposes, the pressure of explosion (PE) is estimated as [26],

$$PE = \frac{1}{2}PD \tag{2}$$

Furthermore, the time dependent borehole wall pressure ($P(t)$) is substantial as a result of explosion. Many researchers indicated functions to obtain $P(t)$ such as [27]-[29]. The transient spherical cavity pressure is represented by the following expression [30], [31],

$$P = P_0\left(e^{-\alpha t} - e^{-\beta t}\right) \tag{3}$$

where P_0 is the peak wall pressure, and α and β are the positive frequency-dependent decay constants which can be calculated by,

$$\alpha = \omega / 4\sqrt{2} \tag{4}$$

$$\beta = \omega / 2\sqrt{2} \tag{5}$$

$$\omega = \frac{2\sqrt{2}C_p}{3a} \tag{6}$$

$$C_p = \sqrt{\frac{K + \left(\frac{4G}{3}\right)}{\rho_r}} \tag{7}$$

where C_p is the P-wave velocity in the rock media, a is the spherical explosive charge radius, K is the bulk modulus of the rock media, G is the shear modulus of the rock media, and ρ_r is the rock density [27], [30].

In the present study, the pressure pulse is induced by detonation of a type of gelatinous explosive with a density of 1.6 gr/cm^3 and detonation velocity of 5900 m/s. Consequently, the input pressure pulse of the numerical modelling has been obtained as shown in Fig. 2.

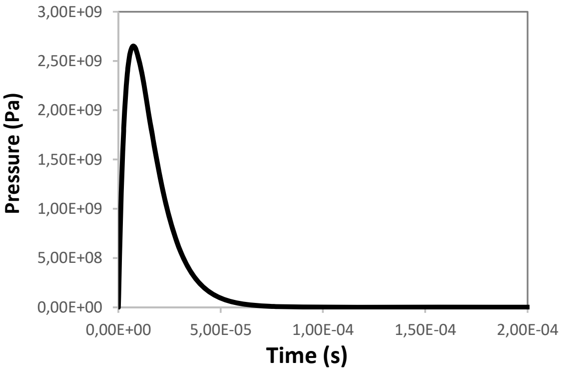

Fig. 2 Explosion pressure pulse

The pressure pulse, shown in Fig. 2, was applied to each location of the separate explosive charges around the wellbore displayed in Fig. 1. Results of the explosions are presented and discussed in the next section.

III. RESULTS AND DISCUSSION

After the explosion was completed, shock wave propagated in the rock media and the induced stresses caused fractures around the wellbore. Fig. 3 shows cracks induced by explosive fracturing procedure around the wellbore.

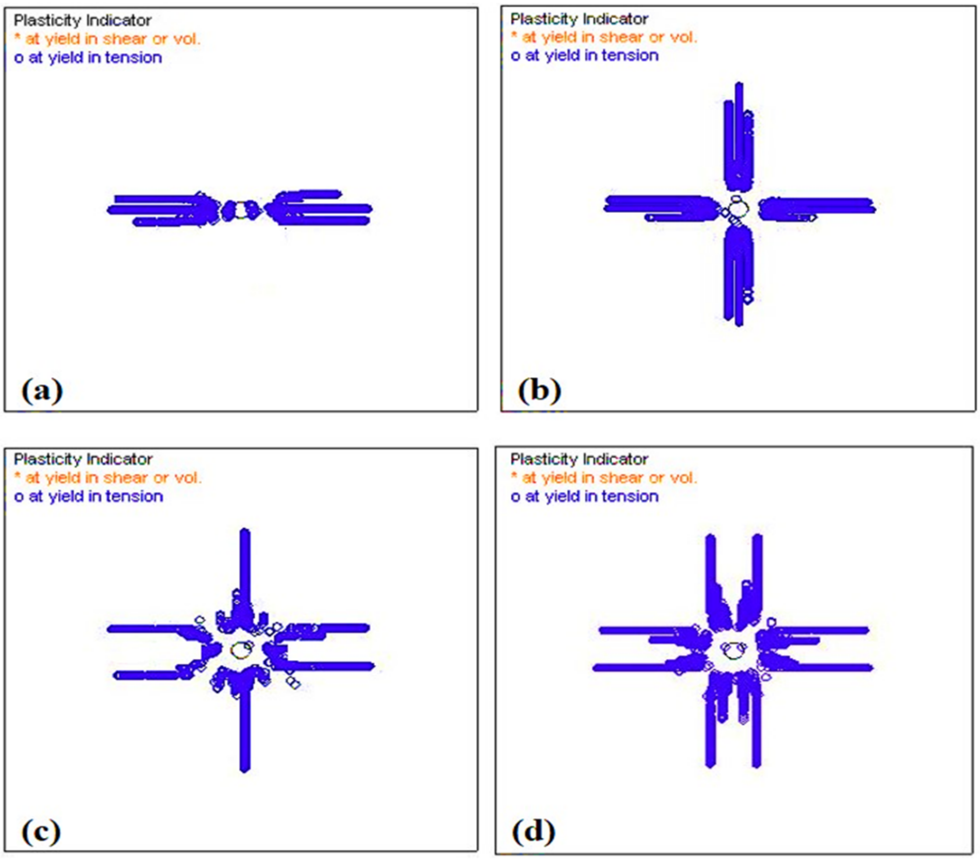

Fig. 3 Explosively fracturing crack patterns around a wellbore with, a) two, b) four, c) six and d) eight separate spherical explosive charge

As can be seen in Fig. 3 (a), two significant fractures from two sides of the wellbore initiated when two explosive charges are exploded simultaneously. At the same way, four explosions on four sides of the wellbore caused to create four significant fractures (Fig. 3 (b)). In Fig. 3 (c), six significant fractures appear around the wellbore due to explosion of six separate explosive charges. There are eight significant fractures around the wellbore after explosion of eight separate charges (Fig. 3 (d)).

IV. CONCLUSION

The explosive fracturing was numerically modeled using two, four, six, and eight separate explosions around a wellbore. A time-marching finite difference technique was utilized to simulate the shock wave propagation in rock media. The shock waves create the induced stresses that caused fractures around the wellbore.

Numerical results show that two significant cracks have been derived from simultaneously explosion of two separate explosive charges around a wellbore. Also in cases of explosion of four, six and eight explosive charges, four, six and eight significant cracks were respectively appeared around the wellbore. It should be noted that in addition to the mentioned significant cracks, there are few cracks which cannot extend as large as the others. Moreover, in the present study, a generic explosion was applied to the numerical models, while, if a stronger explosion is used, the results may be seen more clearly. Also, the fractures pattern and their orientation can be affected by strength of the utilized explosives.

Generally, results indicate that explosion-induced cracks are considerable and can play an important role in increasing the permeability of the oil/gas reservoirs around a wellbore. So, the explosive fracturing can significantly influence on enhancement of the wellbore production and its efficiency. In this study, only crack initiation due to explosion shock wave propagation is investigated, while, the initiated cracks could propagate due to explosion gas expansion in them. Furthermore, the crack patterns resulted in this study can be used in numerical modeling of the crack propagation around the wellbore as crack tip elements.

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