# Optimizing the Design of Cluster Spacing during Volume Fracturing for Tight Formation

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**Abstract—Volume fracturing aiming to induce a complicated fracture network is a key measure to acquire commercial productivity in tight formation where the selection of optimal cluster spacing is important and essential. Therefore，most numerical simulation is mainly used to obtain the optimal cluster spacing, but not often considered with the effect from transverse fractures interference. Based on a new analytical solution methodology for multiple equally spaced stage/cluster transverse fractures, this paper presents a simple and efficient approach added the interference (like flow rate interference, stiffness interference, fluid loss interference ) among multiple transverse fractures to acquire the optimal cluster spacing with the goal of maximizing the oil production. Meanwhile, it results that adequate big cluster spacing is not good to create complex fracture network and much less one easily results in strong effect on production due to fractures interference. The paper provides references for optimizing volume fracturing design and planning rational development strategies in this area.**

***Keywords-Tight oil; Volume fracturing; Cluster spacing; Fractures interference; Optimal design***

## I. INTRODUCTION

Multistage volume fracturing has become the key technology to complete horizontal wells in tight oil reservoirs[1~5]. In each stage, multiple perforation clusters are used to create complicated fracture network for enlarging stimulated reservoir volume(SRV)[6~8]. Most numerical simulation is mainly used to obtain the optimal cluster spacing, but not often considered with the interference among the fractures. Due to the interference, given the same lateral length of a horizontal well, although reducing cluster spacing increases the total number of fractures, smaller cluster spacing does not necessarily improve well performance. Inadequate small cluster spacing can actually lead to a greater number of less-effective or ineffective fractures, and, therefore, lower gas rate and ultimate recovery(Y.Cheng, 2012)[9]. Therefore, based on a new analytical solution methodology, this paper presents a simple and efficient approach added the interference of multiple transverse fractures to acquire the optimal cluster spacing with the goal of maximizing the oil production. Three distinct analytical models are included, like a basic reservoir production model that is based on the transient behavior of a well in a closed reservoir, a hydraulically fractured models employed that are based on a finite conductivity vertical fracture and an analytical method used that was developed by coupling the short time solution with the semi-log asymptotic (pseudo-radial) solution[10].

## II. TRANSVERSE FRACTURE INTERFERENCE MODEL

### A. Multiple equally spaced Stage/Cluster Transverse Fractures.

The system configuration for multiple stage/clusters with equal spaced stages and equal spaced clusters per stage in a closed rectangular reservoir is shown in Fig.1[10].

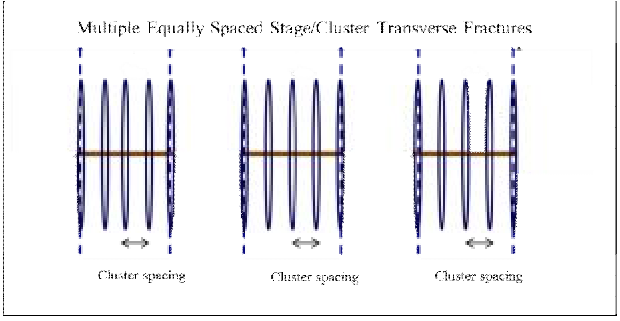

Figure 1. Schematic of a multiple equally spaced stage/cluster transverse fractures

### B. Transverse Fracture Interference

The closer the fractures in any given plane the greater the fracture interference factors and degrees of interference. Only fractures in the same plane are assumed to interact. Dilatancy at the interface is ignored. And stiffness interference is only assumed to occur between fractures in the same plane. Fluid loss interference can occur between planes. The degrees of interference for stiffness and fluid loss are functions of the formation properties and relative position of the multiple fracture system. The individual fracture properties and parameters are identified by the subscript $i$. The total value for N fractures is given by the subscript $T$. The interference functions and degrees of interference are given by $\Psi$ and $\Phi$, respectively. Therefore, the individual fracture interference factors and degrees of interference are shown below[10].

*1) Flow rate interference:* Flow rate interference is defined as

$$Q_i = \Psi_q Q_T \tag{1}$$

Where

$$\Psi_q = 1/N$$

*2) Stiffness interference:* Stiffness interference occurs when fractures are close enough to be affected by the stress field from adjacent fractures. The stiffness factor for each plane is defined as

$$\Upsilon_E(z) = (N_z - 1)\Phi_E \tag{2}$$

Where $\Phi_E$ is the stiffness interference factor and $N_z$ is the number of parallel fractures in that plane that interact. The effective modulus in the $z$ direction is then defined as

$$E_z = \Psi_z E \tag{3}$$

An empirical correlation for the 3D influence factor, $\Phi_{ij}$ is

$$\Phi_{ij} = 1 - 1\Big/\left[1 + \left(\frac{h}{2d_{ij}}\right)^2\right]^{3/2} \tag{4}$$

where $h$ is the fractures height and $d_{ij}$ is the distance between parallel fractures $i$ and $j$.

The average stiffness factor for $N_z$ parallel fractures is

$$\Upsilon_E(z) = \sum_{i=1}^{N_z}\sum_{j=1}^{N_z}\Phi_{ij}\Big/N_z \tag{5}$$

The closer the fractures are together, the greater the stiffness. For multiple parallel fractures within a fraction of their characteristic height, the stiffness increases by a factor equal to the number of fractures. For tree like fractures the stiffness interference may be negligible.

Where

$$\Psi_E = (N-1)\Phi_E + 1$$

*3) Fluid loss interference:* The interference values for no interference and full interference can be assumed to zero and 100%, respectively. Depending on the reservoir properties and vicinity of the fracture system, this fluid loss interference may not be the same as the degree of the stiffness interference.

$$V_i = V_T / N \tag{6}$$

Where

$$V_T = \Psi_l V_0$$

$$\Psi_l = (1-N)\Phi_l + N$$

For non-interacting $\Phi$ fractures, the degrees of interference for stiffness and fluid loss are zero. If the fractures are fully interacting, the $\Phi$ values are equal to unity. Depending on the degree of fracture interference, the fracture net pressure can be lower for multiple fractures than for a single fracture[10].

## III. SIMULATION

The tight oil horizontal well was completed with a eleven-stage fracture treatment (two clusters per stage) over a lateral of 650m. Following the eleven-stage treatment, the well was flowed back and the plugs were drilled out with coil. After the well was cleaned out with coil tubing, a production log was run to determine flow contribution from each stage[11]. The multiple transverse fractures were used to match the production data to get the formation parameters that are regarded as the basic data to simulate and are given in Table 1. The production data was matched with the single phase analytical reservoir simulator for multiple transverse finite-conductivity vertical fractures in horizontal wellbores[12]. The tight oil reservoir and fracture properties parameters are given in Table 2. The simulation of production with different cluster spacing is given in Table 3. Fig. 2 shows a prediction of the cumulative oil production as a function of time. The simulation was based on optimizing the cluster spacing for a maximum cumulative oil production: given the 650m lateral length, 11 stages and two clusters per stage of a horizontal well, 35m cluster spacing was calculated to be optimal. Adequate big cluster spacing is not good to create complex fracture network and much less one results in strong effect on production due to fractures interference.

TABLE 1: The Tight Formation Parameters

| **Formation** | |
|---|---|
| **Permeability (mD)** | 0.18 |
| **Reservoir Capacity (mD·m)** | 3.56 |
| **Fracture** | |
| **Propped length (m)** | 190.00 |
| **Conductivity (mD·m)** | 140.50 |

TABLE 2: Tight oil reservoir and Fracture Properties

| **Formation** | Value |
|---|---|
| **Thickness (m)** | 18 |
| **HC Porosity (%)** | 10 |
| **Pore Pressure (Mpa)** | 18 |
| **Oil Density (g/cm$^3$)** | 0.80 |
| **Drainage Area (km$^2$)** | 0.45 |
| **Aspect Ratio** | 0.40 |
| **Lateral Length (m)** | 650 |
| **Number of Stages** | 11 |
| **Clusters/Stage** | 2 |

TABLE 3: Cumulative oil production with different cluster spacing

| **Cluster spacing (m)** | **Time (yr)** | **Cumulative oil production ($m^3$)** |
|---|---|---|
| 10 | 5 | 7613.04 |
| 15 | 5 | 7614.51 |
| 20 | 5 | 7618.90 |
| 25 | 5 | 7628.19 |
| 30 | 5 | 7629.88 |
| 35 | 5 | 7634.86 |
| 40 | 5 | 7629.12 |
| 45 | 5 | 7633.91 |

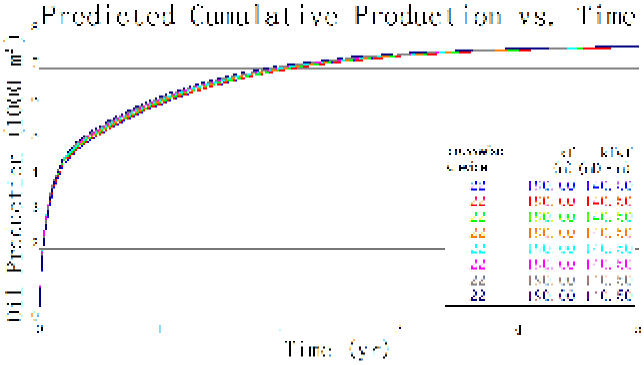

Figure 2. Predicted cumulative production versus time

Table 3 and Fig. 2 illustrates that using the new analytical solution, the optimal cluster spacing is obtained considering the interference among transverse fractures.

## IV. CONCLUSIONS

The analytical solution gives the optimal clustering spacing for tight formation during volume fracturing considering the interference among transverse fractures in terms of maximum cumulative production.

The methodology presented will provide the engineer an approach to make better and more informed decisions when design the cluster spacing in horizontal wellbores.

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