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Optimization of hydraulic fracture geometry in gas condensate reservoirs

H. Mahdiyar [a], M. Jamiolahmady [b,*]

[a] Shiraz University, Shiraz, Iran
[b] Heriot-Watt University, Edinburgh, EH14 4AS, Scotland, United Kingdom

HIGHLIGHTS

- Proposed a new optimization method for hydraulic fracture dimensions.
- It is general and applicable to gas and gas condensate systems.
- Discussed limitations of available methodologies for non-Darcy flow systems.
- Demonstrated superiority of our proposed formulation through various examples.

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ABSTRACT

An optimized design for hydraulic fracturing is of great importance especially with the growing demand for this method as a means of production enhancement from unconventional gas reservoirs. The first Optimum Fracture Design (OFD) approach, which maximizes well productivity for a given fracture volume, was introduced by Prats in 1960 for single-phase Darcy flow systems. This was then further developed and presented in the form of Unified Fractured Design (UFD) charts by Valko et al. (1998), which is applicable to Pseudo-steady state conditions. Later on, some methodologies have been proposed to make UFD applicable to gas condensate systems assuming the distribution of the condensate phase around the fracture as a rectangular damage zone with constant thickness and reduced permeability. These latter methods are generally oversimplified as they neglect different possible shapes of the two phase region around the fracture and the variation of relative permeability with interfacial tension (IFT) and velocity for these low IFT systems. They also require data that are not readily available, in particular the pressure profile (required to identify the two-phase boundary) around the wellbore.

In this paper, we introduce an explicit formulation and a more general methodology for OFD that is applicable to both Steady state and Pseudo-steady state single-phase gas and two-phase gas condensate flow systems and includes the important flow parameters in both the matrix and fracture. The optimum fracture dimensions are obtained by maximizing the effective wellbore radius, using the recently developed correlation by Mahdiyar et al. (2011). This formulation accounts for the mechanical and flow skins based on quite readily available information at wellbore conditions.

The integrity of the introduced formulation has been verified for many different prevailing conditions, whilst highlighting the errors of using conventional approaches with some important practical guidelines. In this exercise, the maximum productivity calculated using the proposed formulation is compared with results of the literature or our in-house simulator. This program, using a fine grid approach, simulates gas condensate flow around a hydraulically fractured well for various fracture length–width ratios and identifies the optimum fracture dimensions, for a given fracture volume, providing maximum mass flow rate.

1. Introduction

Optimization of a hydraulic fracture geometry provides the maximum productivity/injectivity of a hydraulically fractured well (HFW) for a fixed fracture volume.

Prats [18] was the first to introduce the concept of the optimum fracture geometry. According to his results, optimum fracture

* Corresponding author. Address: Heriot-Watt University, Institute of Petroleum Engineering, Riccarton, Edinburgh, EH14 4AS, United Kingdom. Tel.: +44 131 4513122; fax +44 131 4513127.

E-mail address: jami.ahmady@pet.hw.ac.uk (M. Jamiolahmady).

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Nomenclature

A	a parameter, showing the effect of fracture penetration ratio on effective wellbore radius at Steady state
B	a parameter, showing the effect of fracture penetration ratio on effective wellbore radius at Pseudo-steady state
$(a,b,c)_{SS}$	parameters of F_{SS}
$(a,b,c)_{PSS}$	parameters of F_{PSS}
C	a constant in J_D expression, Eq. (2), which is 1/2 for Steady state systems and 3/4 for Pseudo-steady state
C_{fD}	bsolute fracture conductivity
$C_{fD\text{-}eff}$	effective fracture conductivity
f_A	function varying with parameter A.
f_B	function varying with parameter B.
F_{SS}	Steady state function
F_{PSS}	Pseudo-steady state function
h	formation thickness
I_X	fracture penetration ratio, x_f/x_e
J_D	dimensionless productivity index
k	absolute reservoir permeability
k_f	absolute fracture permeability
k_r	relative permeability
m	mass flow rate
P	pressure
q	volumetric flow rate at bottom-hole conditions
r	radius
r'_w	effective well bore radius
Re	Reynolds number
S'_f	pseudo fracture skin factor
V_f	facture volume per unit height of the fracture
V_e	drainage volume per unit height of the fracture
w_f	fracture width
x_e	half length of the square drainage area
x_f	half length of the fracture
M	mass mobility
MR	mass mobility ratio

Symbols

δ	a parameter defined in Eqs. (4)–(6)
β	single-phase inertial factor
μ	viscosity
ρ	density
Ψ	pseudo pressure
$\bar{\mu}$	average viscosity based on GTR
$\bar{\rho}$	average density based on GTR

Subscripts

b	base
c	condensate
D	dimensionless
e	external as in r_e
eff	effective
f	fracture
g	gas
m	matrix
opt	optimum
r	relative
w	wellbore

Abbreviations

C_1	methane
C_4	normal butane
C_{10}	normal decane
EOH	equivalent Open-hole
EOS	equation of state
GTR	gas to total (gas plus condensate) flow rate ratio.
IFT	interfacial tension
HFW	hydraulically fractured well
HF	hydraulic fracture
HFWS	hydraulically fractured well system
OH	open-hole
PR3	3 parameter Peng Robinson EOS
SS	Steady state
PSS	Pseudo-steady state

design for a HFW in a square drainage area under the Darcy flow regime is obtained when dimensionless fracture conductivity, that is the ratio of flow ability of the fracture (the permeability-width product) over that of the matrix (the permeability-fracture-half length product), is 1.26.

Valko et al. [20] presented an optimization approach called Unified Fracture Design (UFD). They emphasize that "the key to formulating a meaningful technical optimization problem is to realize that penetration and dimensionless fracture conductivity are competing for the same source: the propped volume". In the UFD method, the propped number is introduced as two times of the ratio of the propped volume to the reservoir volume, weighted by their permeability contrast. Fracture conductivity is defined as the ratio of ability of the fracture to pass flow to the wellbore to that of the matrix to pass it to the fracture, i.e. the ratio of fracture permeability, width product to matrix permeability, fracture half length product. Their charts present the dimensionless productivity index (a measure of well deliverability) of Hydraulically Fractured Wells (HFWs) at Pseudo-steady state (PSS) as a function of dimensionless propped number and fracture conductivity. In these graphs, it is clearly shown that for each propped number there is an optimum fracture conductivity at which the productivity index has the maximum value.

Economides et al. [1] in discussing the optimal design stated that "...what is good for maximizing PSS flow is also good for maximizing transient flow".

A semi-analytical formula for estimation of effective wellbore radius of a HFW in a rectangular closed drainage area for single-phase Darcy flow at PSS was developed by Meyer and Jacot [16]. They also presented a chart, which correlates the optimum fracture conductivity, for drainage area with rectangular aspect ratio, with a restriction for fracture penetration ratio; i.e. the chart is applicable for HFWs with fracture penetration ratio less than 0.2. According to the results of Meyer and Jacot [16] and also Valko et al. [20], optimum fracture conductivity in square drainage areas (with I_x less than 0.2) is about 1.57, which is a little higher than the Prats suggested value of 1.26.

The optimization of hydraulic fracture in a non-Darcy flow system has also been the subject of study by some investigators. Lopez-Hernandez et al. [13] introduced the concept of using the effective propped number in the UFD method for estimation of optimum fracture length for non-Darcy flow systems. In this concept, as inertia reduces absolute fracture permeability, effective permeability should be used in the calculation of propped number and fracture conductivity.

There are also publications available in the literatures [21,8,17] on optimization of fracture design for gas condensate systems. However, in all these studies gas condensate flow has been treated as a single phase flow with a fracture face damage related to a constant thickness two phase region around the whole fracture. For instance, Wang et al. [21] used the Cinco-Ley skin equation,