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Research Article

Naturally Fractured Reservoirs – Yet an Unsolved Mystery

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Abstract: Some of the world's most profitable reservoirs are assumed to be naturally fractured reservoirs (NFR). Effective evaluation, prediction and planning of these reservoirs require an early recognition of the role of natural fractures and then a comprehensive study of factors which affect the flowing performance through these fractures is necessary. As NFRs are the combination of matrix and fractures mediums so their analysis varies from non-fractured reservoirs. Matrix acts as a storage medium while mostly fluid flow takes place from fracture network. Many authors adopted different approaches to understand the flow behavior in such reservoirs.

In this paper a broad review about the previous work done in naturally fractured reservoirs area is outlined and a different idea is initiated for the NFR simulation studies. The role of capillary pressure in natural fractures is always been a key factor for accurate recovery estimations. Also recovery through these reservoirs is dependent upon grid block shape while doing NFR simulation. Some authors studied above mentioned factors in combination with other rock properties to understand the flow behavior in such reservoirs but less emphasis was given for checking the effects on recovery estimations by the variations of only fracture capillary pressures and grid block shapes. So there is need to analyze the behavior of NFR for the mentioned conditions.

Keywords: Naturally fractured reservoirs, capillary pressure, grid block shape

1. INTRODUCTION

Naturally fractured reservoirs (NFR's) have great importance and differ from conventional reservoirs as these contain fractures throughout the reservoir. These reservoirs usually have low matrix permeability and high fracture permeability having oil or water wet rock properties which may results in low recovery. So good understanding of flow behavior is required to optimize recovery process. Analysis and simulation of fractured reservoirs are done by dividing such reservoirs into matrix and fracture systems. Initially dual porosity concept was introduced but now a day's dual porosity and dual permeability approach for performing NFR simulation studies is widely accepted.

2. LITERATURE REVIEW

From 1960's naturally fractured reservoirs acquired great importance for recovery considerations. Barenblatt et al [1] firstly introduced the dual medium model for the simulation of naturally fractured reservoirs. Analysis was done by assuming that the total fluid flow is a combination of flow both from matrix and fracture. In 1963, Warren and Root [2] worked on the naturally fractured systems and by assuming primary porosity as a storage medium of fluid having very low flowing capacity, an idealized model was developed for analysis of fluid flow such reservoirs . During this flow, matrix blocks continuously feed the fracture system but fluid cannot move directly from one matrix to other matrix

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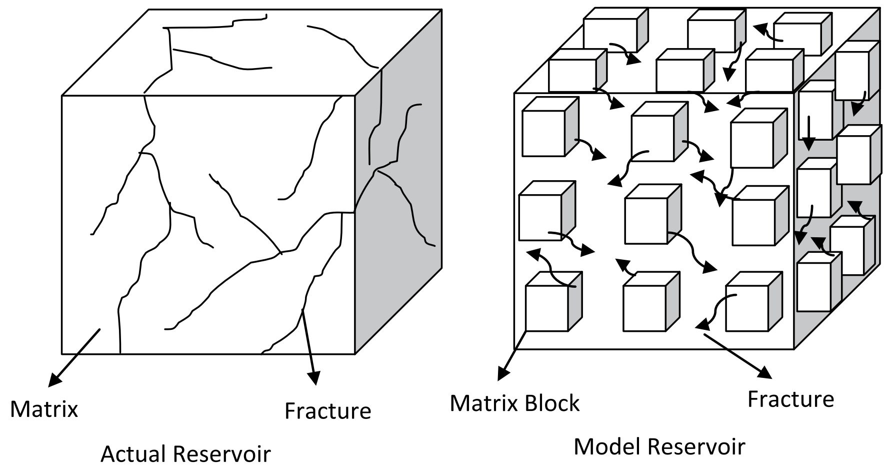

Fig. 1. Idealized fractured system.

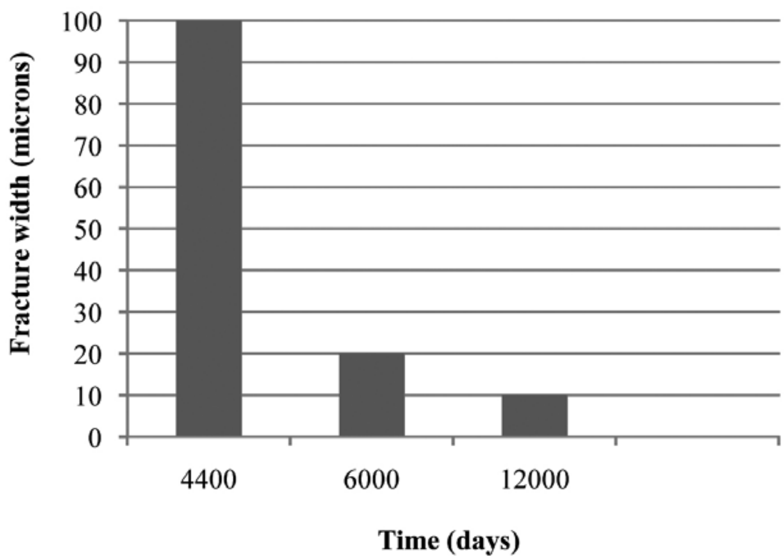

Fig. 2. Time taken to achieve total recovery for different fracture widths.

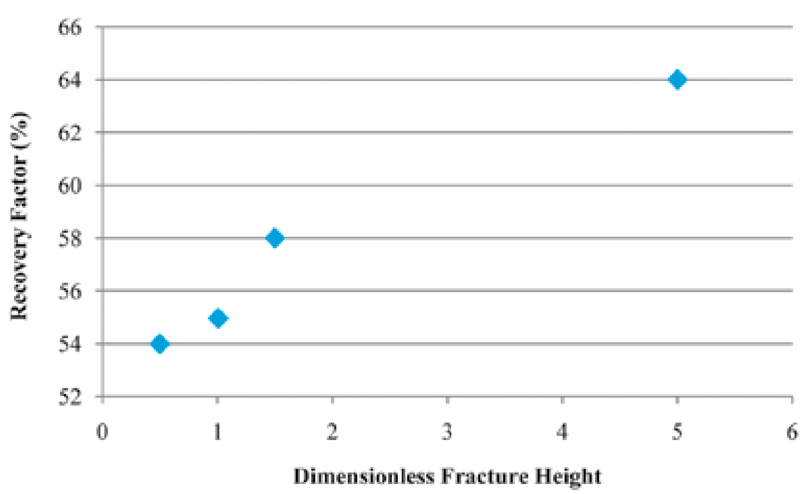

Fig. 3. Recovery factor for different dimensionless fracture height.

block (Fig. 1). Unsteady state flow and pressure built up performance had also been examined and suggested that two parameters, interporosity flow parameter (λ) and fluid storativity ratio (ω) are important for the NFR simulation studies.

In 1976, Reiss [4] worked to develop understanding about fractured reservoirs. He studied different fracture parameters such as facture permeability, fracture width, fracture porosity etc, depending upon different geometrical systems in reservoirs. He also highlighted different techniques which can be used for the identification of fractures in reservoir. Van Golf Racht [6] in 1982 published a book which comprised of detailed analysis of fracture characteristics. He discussed different fracture properties like fracture permeability and capillary pressures which exists in such reservoirs and concluded that capillary forces may contribute or may oppose fluid flow during imbibitions and drainage process. He suggested that accurate knowledge of matrix and fracture properties is necessary to get truthful results while simulating naturally fractured reservoirs. Saidi [7] suggested that due to capillary effects in vertical fractures and wettability, capillary pressure in fractures could exist. He also recommended that due to blocks interactions, capillary re-infiltration phenomenon which is the fluid flow from upper to lower blocks should be considered for better simulations results.

In 2007, Jadoon et al [13] investigated the carbonate fractured reservoir in *Kohat/Potwar* region, Pakistan. They discussed the problems during the identification of natural and induced fractures, categorized the fractures into conductive, resistive, systematic and unsystematic based on borehole imaging tool and recognized the impact of fractures on production.

3. SIMULATION STUDIES

In 1966, Romm [3] was the first person who performed the experimentation studies to analyze fluid flow in fractured media. His findings showed that a linear relationship exists between phase relative permeability and phase saturation while considering zero fracture capillary pressure. Gilman and Kazemi [5] extended the work of Warren and Root [2] by introducing a shape factor, as given in equation (1). They worked on dual porosity simulator by giving more importance to gravity and capillary interactions. They proposed that no particular method exist which can determine facture capillary pressure and also maximum fracture and matrix capillary pressure must be equal for balanced gravity and capillary forces.

$$\sigma = \frac{1}{4}\left(\frac{1}{L_x^2} + \frac{1}{L_y^2} + \frac{1}{L_z^2}\right) \quad (1)$$

In 1990, Firoozabadi and Hauge [8] analyzed capillary pressure in naturally fractured reservoirs. They proposed a model which relates the existence of capillary pressure in fractures and phase saturation by considering two fracture parameters, aperture and roughness. Through experimental work they indicate the presence of non-zero capillary pressure in fractures. In 2001, Akin [9] analyzed fracture network system with the help of history matching experimental data and numerical model to get the fracture relative permeability. During his analysis, he used different matrix and fracture capillary pressures combinations to obtain the best production and pressure history match. De la Porte et al [10] in 2005 did their analysis on capillary pressures in fracture network system. Two different fluid injection scenarios were analyzed by considering different fracture properties like fracture width and dimensionless fracture height and examined the variations on recovery. Results shows that total recovery is achieved in early times when fracture width is increased and maximum recovery took place for greatest dimensionless fracture height (Fig. 2, 3).

Qasem et al [11] investigated capillary imbibition effects on recovery in partially fractured reservoirs. During analysis, they implemented low and high water injection scenarios and concluded that generally fracture intensity (FI) has a direct impact on recovery as it decreases with low FI for a particular high water injection rate and acts inversely for reverse conditions. They also proposed that counter-current capillary imbibition phenomena occur for high fracture intensity reservoirs during low water injection rates which cause an increase in recovery due to higher areal sweep efficiency and later breakthrough and co-current capillary

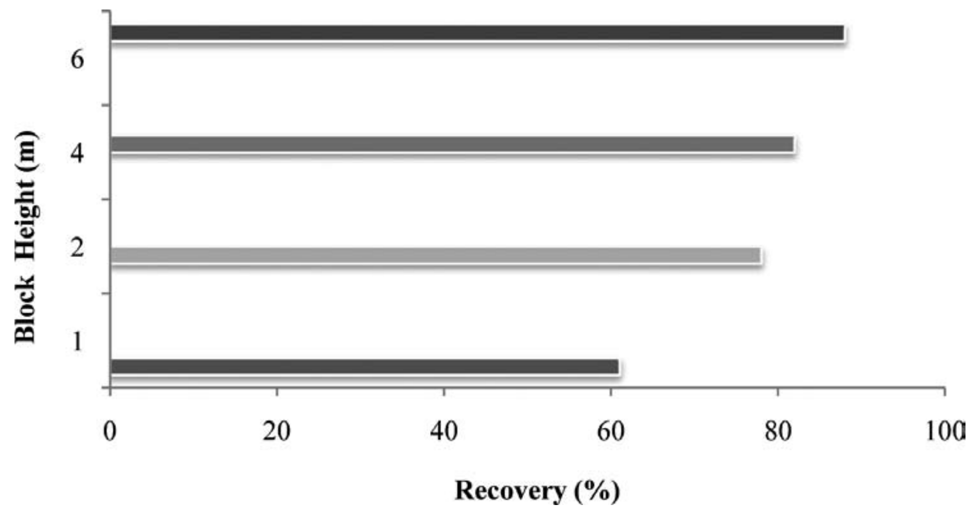

Fig. 4. Ultimate recovery achieved for different block height.

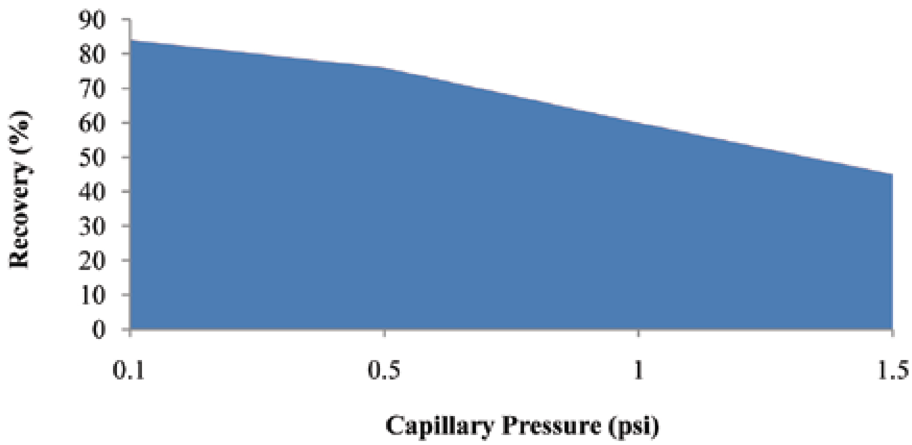

Fig. 5. Inverse relation existing between recovery and capillary pressure.

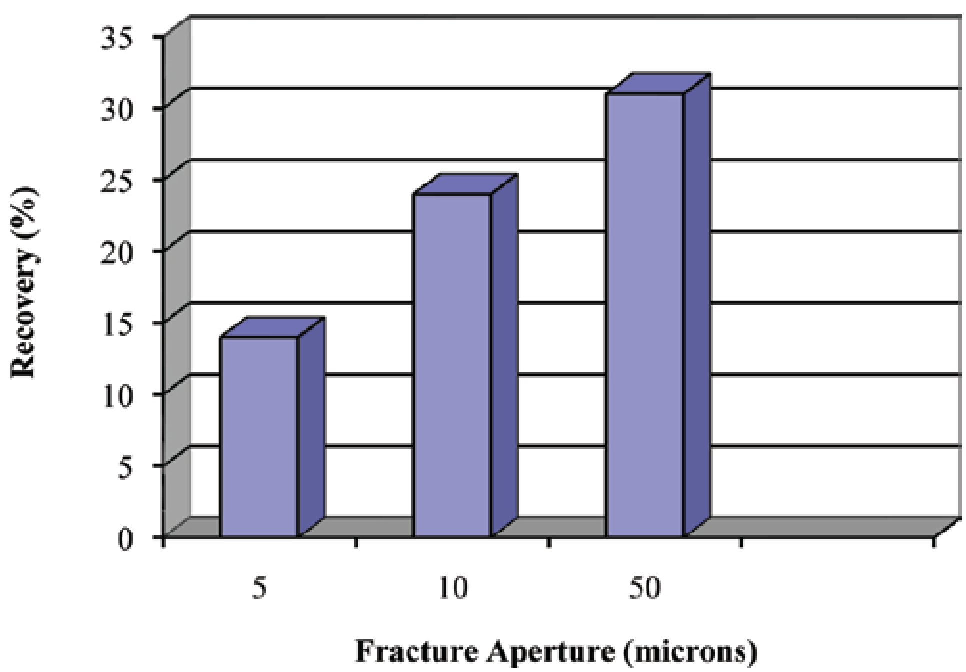

Fig. 6. Comparison of field oil recovery for different fracture widths.

imbibition phenomena occur on low fracture intensity reservoirs thus decreases recovery. Sharait et al [12] studied NFR for oil/gas system having immobile water. They accepted that re-infiltration term effects on production rate but it could not change ultimate recovery. They also suggested that because of matrix block interactions recovery acts as independent from vertical fracture permeability and an early ultimate recovery is achieved when fracture capillary pressure is increased. By increasing the block height oil recovery is increased and an inverse trend exists between matrix capillary pressure and oil recovery (Fig. 4, 5). The reason is that when capillary force increases in matrix less oil will drain to fracture.

In 2007, Tajdar et al [14] in their work highlighted the importance and effects of matrix sub-gridding on recovery in naturally fractured reservoirs. They utilized the technique of dividing a single matrix block into several subgrids so that a more accurate transmissibility of fluid between matrix and fractures could occur. They analyzed different scenarios and concluded that in some cases there could be an error in recovery estimation if improper sub-gridding of matrix block is done. In their analysis variation of fracture properties like fracture capillary pressures are not being discussed.

Uleberg and Kleppe [15] in 2010 did their analysis for the simulation of fractured reservoirs based on physical characteristics of reservoir and fluid flow mechanism in them. They showed that capillary continuity of blocks increase the ultimate recovery. They emphasized to model fractured reservoirs on the source of multiple grid concepts for better results. From this study it can be concluded that the existence of capillary pressure in the fracture system will also affect the recovery. In 2010, Noroozi et al [16] investigated the similar sort of work done by De la porte [10] by considering instead of single porosity single permeability model to dual porosity dual permeability concepts. He focused his work on water and gas injection scenarios while simulating the fractured reservoirs by changing the capillary pressures, fracture width and fracture height. (Fig. 6) shows that when fracture aperture is increased from 5 to 10 microns, recovery is almost doubled.

In 2010, Kiasari et al [17] studied the effects of rock fluid properties during SAGD production and showed that capillary pressure helps in steam penetration from fractures into matrix blocks under water wet condition and act vice versa in oil wet systems. Also an increased early production occurred when capillary pressure is increased from zero. Famian and Masihi [18] in 2010 studied the influence of different properties on recovery while applying immiscible gas injection and during natural depletion. Results indicated that recovery is much affected by matrix threshold capillary pressure and matrix block height.

In 2010, Lemonnier and Bourbiaux [19] described the brief history about the simulation of naturally fractured reservoirs. They discussed different driving mechanism which effect on recovery in fractured reservoirs. In this paper, the use of dual porosity simulator is also been discussed in detail. Jabbari and Zeng [20] in 2011 analyzed the behavior of naturally fractured reservoirs under stress sensitive conditions. Production creates the pressure depletion which may results in changing the characteristics of fractures. So they proposed a model which includes the use of geo-mechanical and fluid flow factors while simulating NFR. The effect of stresses on pressure build up and drawdown curves is also discussed.

4. CONCLUSION AND RECOMMENDATIONS

This study signifies the importance of fracture capillary pressure and grid block shape in recovery estimations. As a conventional practice, the recovery estimations have been made by changing fracture properties such as fracture width, dimensional fracture height, etc while keeping the same grid block shape (mostly cubical). Furthermore, facture capillary pressure effects are not incorporated while conducting simulation studies, which may lead to inaccurate estimations. So, there is an immense need of study to analyze the effects of varying fracture capillary pressure from zero to other numeric values while keeping the same other fracture properties. In addition, the variations in the grid block shape other than cubical must also be analyzed for better representation of reservoirs while numerical modeling for recovery estimations. Consequently, the conducted numerical or simulation studies can lead to improved recovery estimations and, thus, result in better field development planning and economical analysis.

5. NOMENCLATURE AND ABBREVIATIONS

NFR	Naturally fracture reservoir
FI	Fracture intensity
SAGD	Steam assisted gravity drainage
L_x	Length of matrix block in x-direction
L_y	Length of matrix block in y-direction
L_z	Length of matrix block in z-direction
σ	Shape factor

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