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جامعة خليفة
Khalifa University

Matrix-fracture flow transfer in fractured porous media: experiments and simulations

Jiafan Guo
Northeastern University
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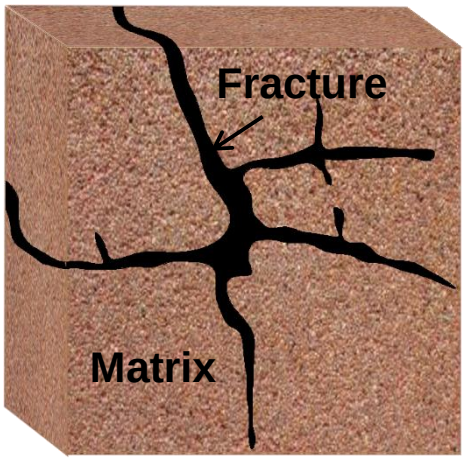
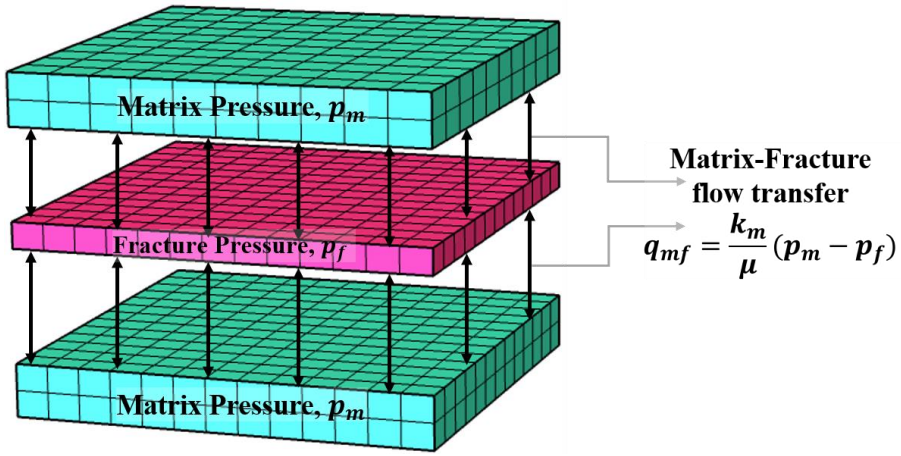
OUTLINE

1. Introduction
2. Experiments of matrix-fracture transfer
3. Generalized flow transfer model
4. Effect of influencing factors
5. Concluding remarks

1. Introduction



Matrix and fracture structure in fractured porous media

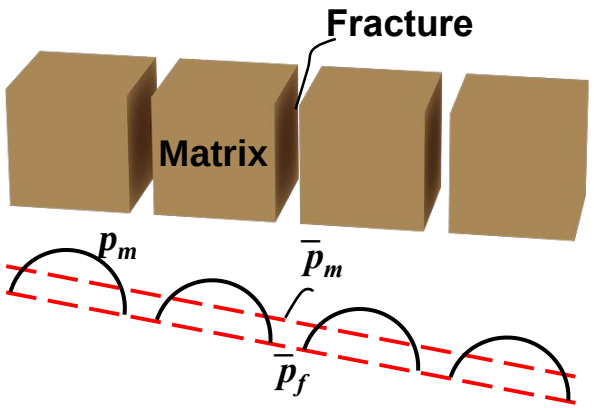


Matrix-fracture flow transfer

- The matrix-fracture flow transfer is one of the most important characteristics of flow in fractured porous media
- When the fluid pressure on matrix is different from that on the fracture, the fluid will transfer from matrix to fracture, or vice versa
- The phenomenon is usually described using a transfer function

1. Introduction

❖ Transfer function in dual-porosity model



Warren and Root model (1963)

Transfer function:

$$q_{mf} = \sigma \frac{k_m}{\mu}\left(\overline{p_m} - \overline{p_f}\right)$$

Where: p_m= average matrix pressure;

$\bar{p}_f$ = average fracture pressure;

σ =shape factor (1/L^2).

Values of dimensionless shape factors σL^2

References	σL^2
Warren-Root (1963)	60
Kazemi et al. (1976)	12
Coats (1989)	49.58
Zimmerman et al. (1993)	29.61
Lim and Aziz (1995)	29.61
Sarda et al.(2001)	48
Hassanzadeh and Pooladi-Darvish (2006)	25.56
Mora and Wattenbarger (2009)	25.67
Hassanzadeh et al. (2009)	25.67
Peyman et al. (2020)	15.6

Note: L=characteristic length of the matrix

◆ It is ambiguous for engineers to apply these findings in practice

◆ It's need to propose a generalized Matrix-fracture transfer function with consistent parameters

1. Introduction

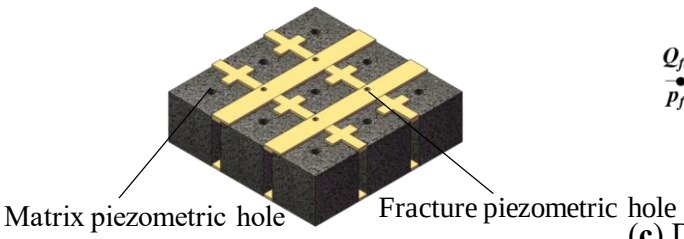
❖ Content of the study

Variable flow transfer direction in fractured porous media with complex geometry

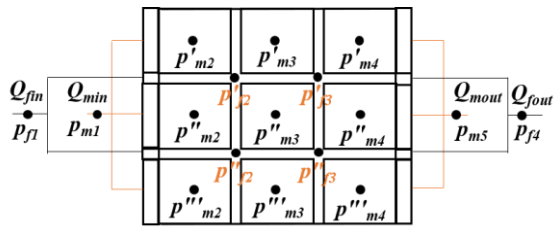
- Study of matrix-fracture flow transfer by experiment and simulation
- Matrix-fracture flow transfer model
- Investigate the influence of the fracture occurrence and fracture-matrix permeability ratio on matrix-fracture flow transfer

2. Experiments of matrix-fracture transfer

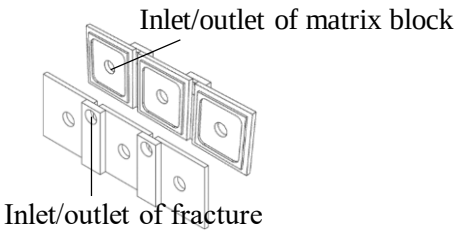
❖ Test equipment



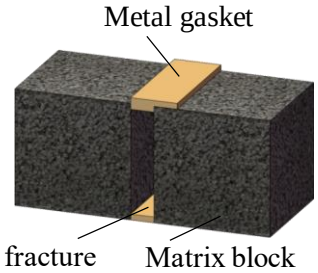
(**b**) Piezometric holes and FPM model



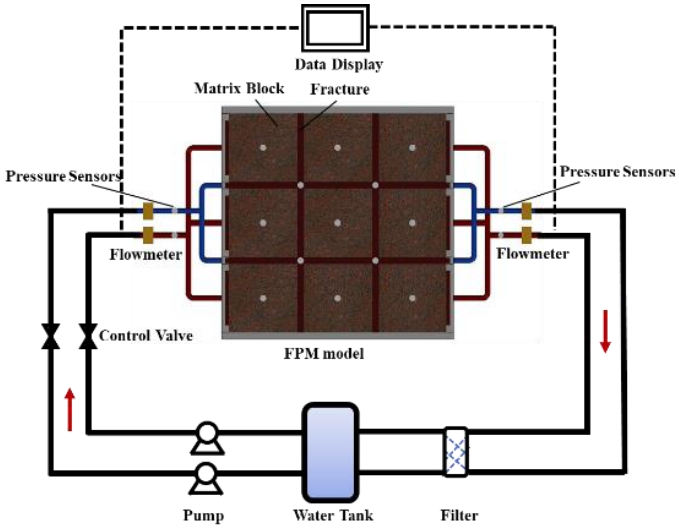
(**c**) Distribution of pressure sensors(p_{mi};p_{fi}) and flowmeter (Q_{mi};Q_{fi})



(**d**) Inlet/outlet of FPM model



(**a**) Fracture model



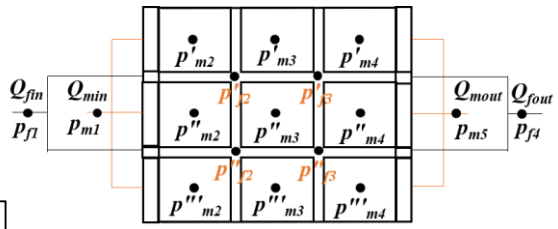
Schematic diagram for matrix-fracture flow transfer in FPM

(**e**) FPM model after sealed

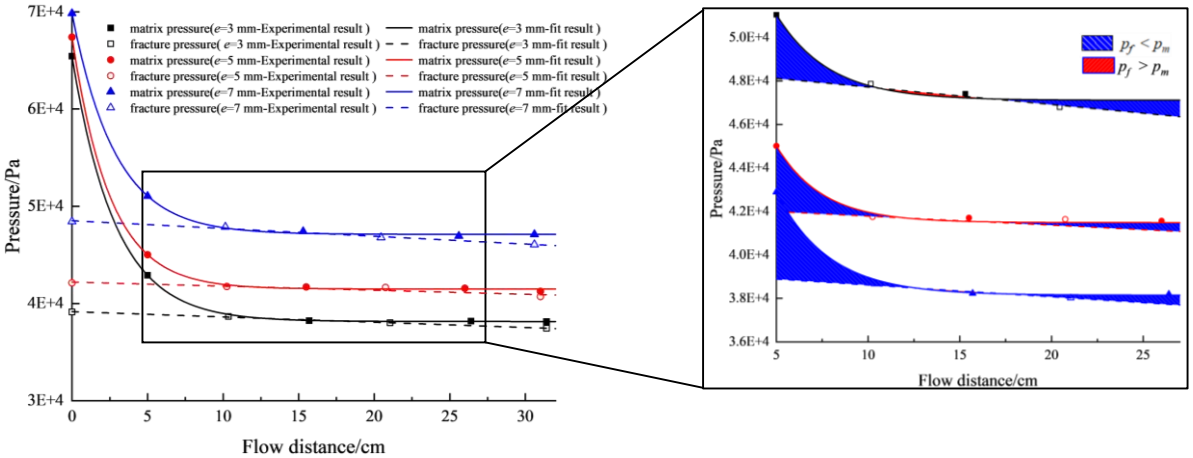
- FPM model consists of 9 cubic matrix blocks and 4 mutually orthogonal fractures
- Parameters: e =3 mm; e =5 mm; e =7 mm (V_m=100×100×100 mm^3; k_m=1.47×10^{-4} m/s)

2. Experiments of matrix-fracture transfer

❖ Experimental results and discussion



➢ Pressure distribution of matrix and fracture

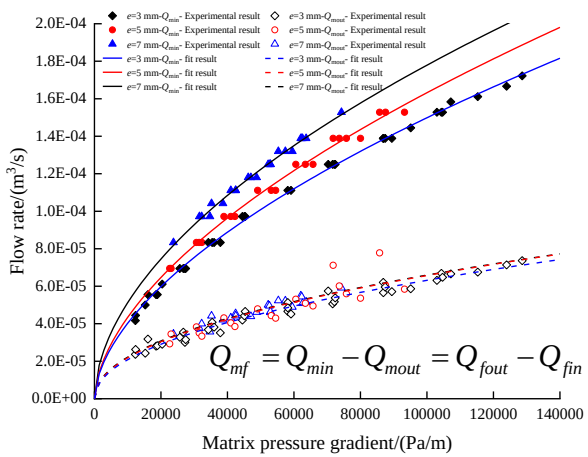


Pressure distribution of FPM

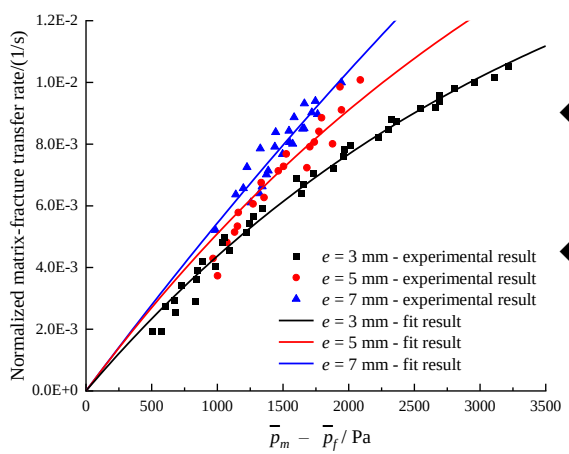
Two-way matrix-fracture flow transfer

- More than 90% of the pressure drop is concentrated in the first half of the flow distance
- Matrix-fracture flow transfer mainly occurs in the first half of the flow distance

➢ Distribution of outlet flow rate



The matrix pressure gradient and flow rate



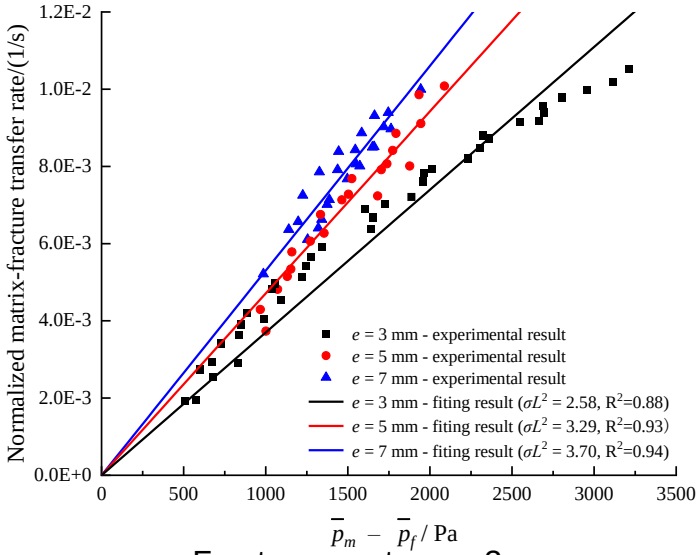
The matrix-fracture pressure difference and transfer

- The matrix-fracture flow transfer rate accounts for 43%~63% of the matrix inlet flow rate
- The normalized matrix-fracture flow transfer rate increases with fracture aperture, matrix-fracture pressure difference

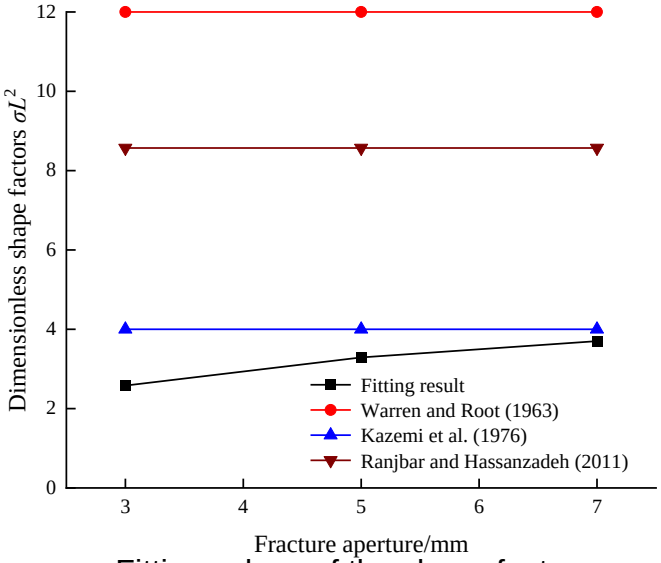
2. Experiments of matrix-fracture transfer

❖ Matrix-fracture transfer rate

➢ Transfer function with shape factor



Fracture aperture *e*=3mm



Fitting values of the shape factor

Transfer function: $$q_{mf} = \sigma \frac{k_m}{\mu}\left(\overline{p_m} - \overline{p_f}\right)$$

◆ The shape factor increases with increasing fracture aperture (2.58~3.70).

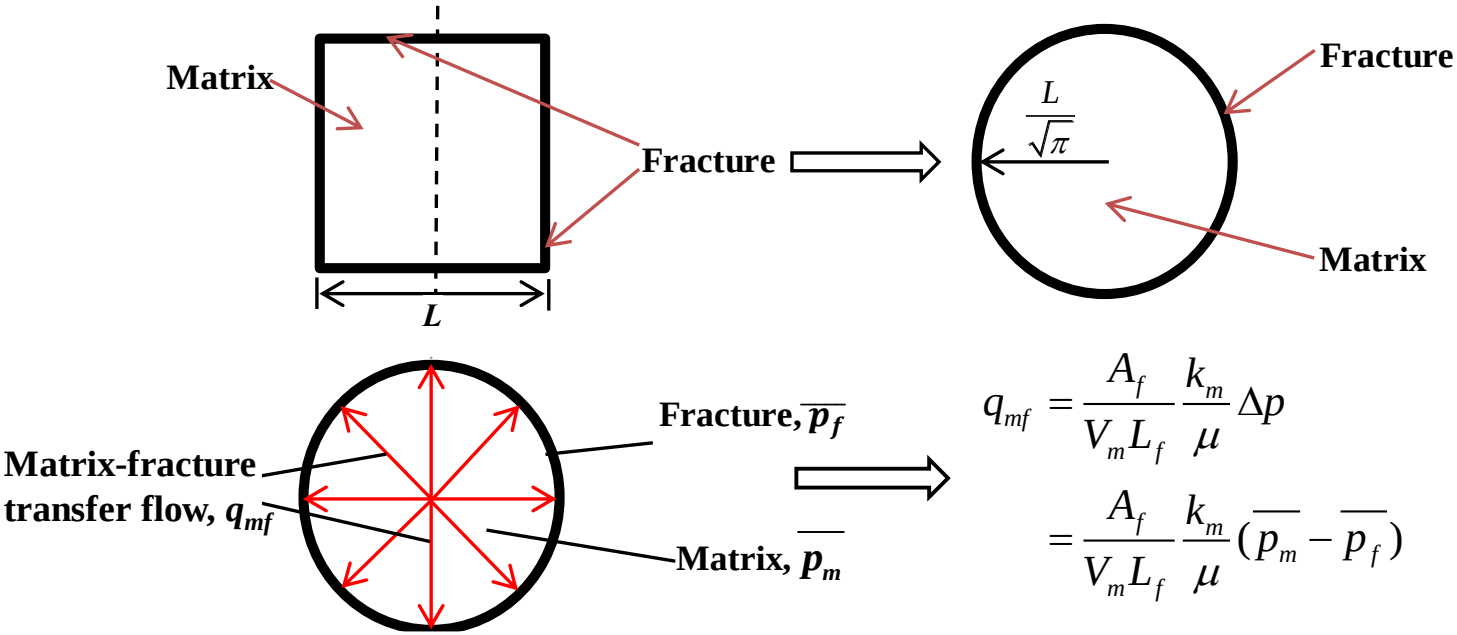
◆ The prediction of the Kazemi model is better than that of Warren-Root model.

◆ The predictions gradually becomes worse as $\overline{p}_m$- $\overline{p}_f$ increases

3. Generalized flow transfer model

❖ A generalized matrix-fracture flow transfer model

➢ Ideal matrix-fracture flow transfer



$$q_{mf} = \frac{A_f}{V_m L_f}\frac{k_m}{\mu}\Delta p = \frac{A_f}{V_m L_f}\frac{k_m}{\mu}(\overline{p_m} - \overline{p_f})$$

Schematic of ideal matrix-fracture flow transfer

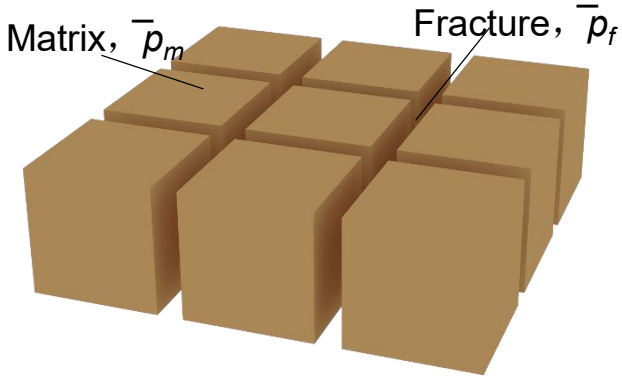
Assumptions:

- ◆ Transfer flow occurs at the matrix/fracture interface
- ◆ Flow transfer is at steady state
- ◆ The matrix-fracture transfer flow is governed by Darcy's law
- ◆ The flow in the entire block are assumed to be one-way

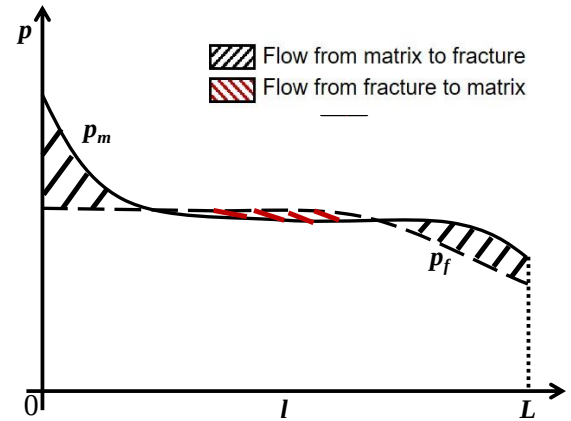
3. Generalized flow transfer model

❖ A generalized matrix-fracture flow transfer model

➢ Matrix-fracture flow transfer with regularly distributed fractures



Fractured porous media



matrix-fracture flow transfer
with heterogeneous fluid pressure

Ideal flow transfer:

$$q_{mf} = \frac{A_f}{V_m L_f} \frac{k_m}{\mu} (\overline{p_m} - \overline{p_f})$$

heterogeneous fluid pressure ⇩ fracture pressure correction coefficient α

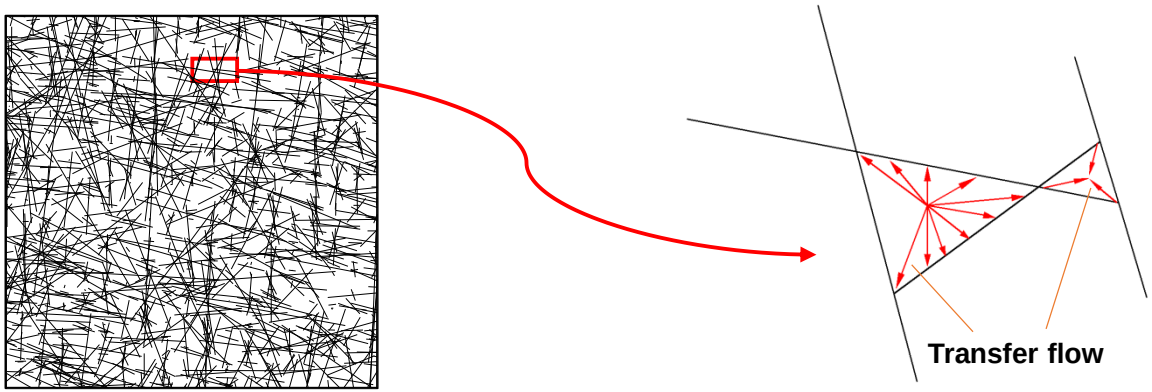
$$q_{mf} = \frac{A_f}{V_m L_f} \frac{k_m}{\mu} (\overline{p_m} - \alpha \overline{p_f})$$

Where: $\overline{p_m} - \alpha \overline{p_f}$ = effective pressure difference between matrix and fracture;

3. Generalized flow transfer model

❖ A generalized matrix-fracture flow transfer model

➢ Matrix-fracture flow transfer with irregularly distributed fractures



Schematic of matrix-fracture flow transfer with irregularly distributed fractures

Ideal transfer flow: $q_{mf} = \frac{A_f}{V_m L_f} \frac{k_m}{\mu} (\overline{p_m} - \overline{p_f})$ $\xrightarrow{\text{heterogeneous pressure}}$ $q_{mf} = \frac{A_f}{V_m L_f} \frac{k_m}{\mu} (\overline{p_m} - \alpha \overline{p_f})$

Natural rock $\Downarrow$ $\boxed{\frac{A_f}{V_m L_f} \rightarrow \frac{1}{l_c^2}}$

Generalized flow transfer model: $$q_{mf} = \frac{1}{l_c^2} \frac{k_m}{\mu} \left(\overline{p_m} - \alpha \overline{p_f} \right)$$

Where: l_c = Characteristic trace length of fractures;

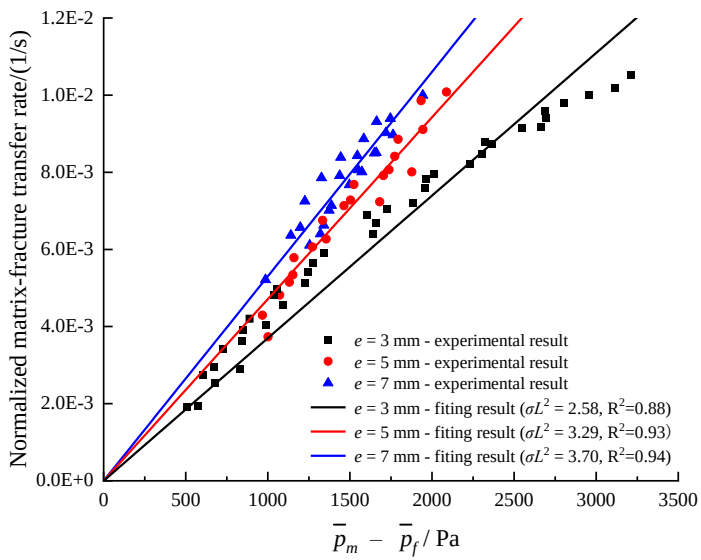
$\overline{p_m} - \alpha \overline{p_f}$ = Effective pressure difference between matrix and fracture;

3. Generalized flow transfer model

❖ Verification of generalized matrix-fracture flow transfer model

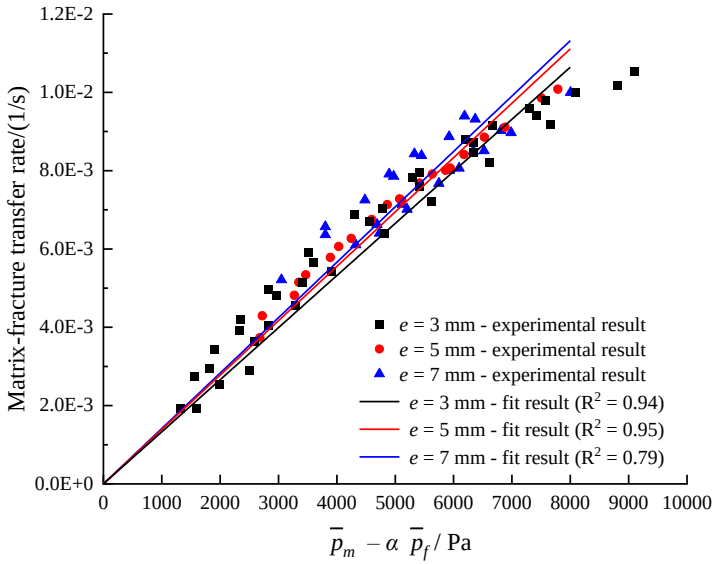
➢ Generalized matrix-fracture flow transfer model

$$q_{mf} = \frac{1}{l_c^2}\frac{k_m}{\mu}\left(\overline{p_m} - \alpha\,\overline{p_f}\right)$$



Shape factor model

Effective pressure difference



Generalized transfer model

◆ The flow transfer rate has a linear relationship with the effective matrix-fracture pressure difference, but it cannot reflect the influence of the fracture aperture

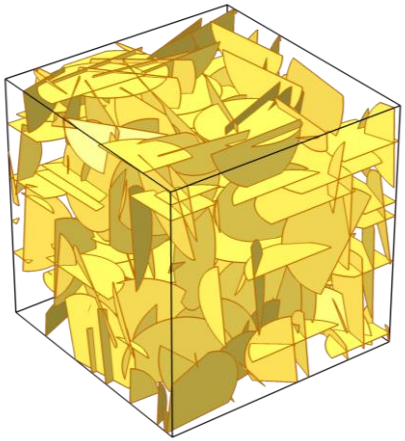
4. Effect of influencing factors

❖ Simulation method

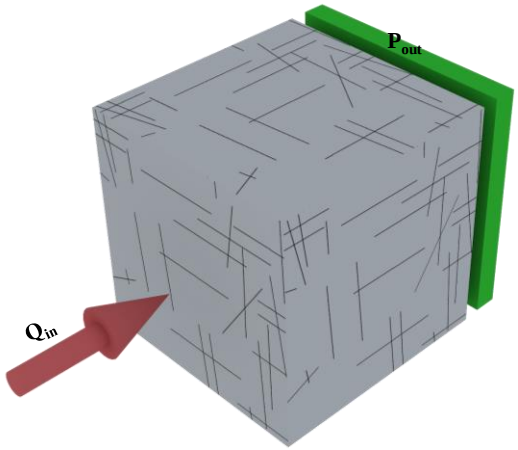
➢ The parameter values of fracture network (Hitchmough et al., 2007)

parameter	Trace length/m	Dip angle/°	Dip direction/°	Density/(pieces/m^{-3})	aperture/mm
Mean	4	3, 89,85	90,265,351	0.1	0.2
Variance	0.1	1,8,10	5,29,14	—	—
Distribution	Normal	Normal	Normal	—	—

➢ Geometrical model and boundary conditions



Geometrical model
(10×10×10 m)



Boundary conditions

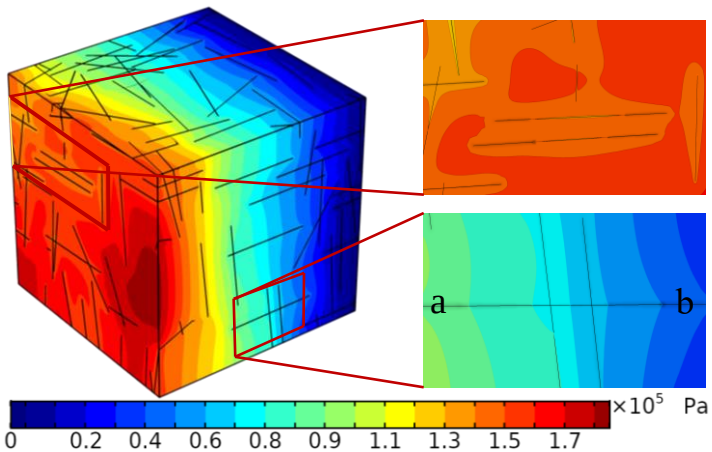
➢ Simulation cases performed in this study

NO.	Trace length/m	Density/ (pieces/m^{-3})	K_f/k_m
1	4	0.1	10000
2	3.5	0.1	10000
3	4.5	0.1	10000
4	4	0.05	10000
5	4	0.15	10000
6	4	0.1	5000
7	4	0.1	20000

4. Effect of influencing factors

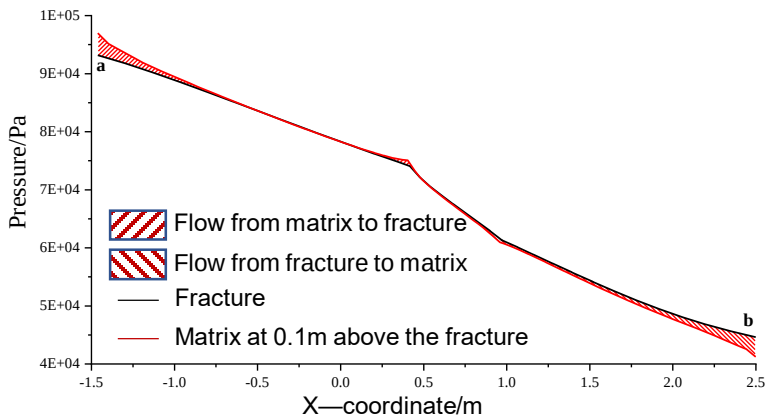
❖ Simulation results and discussion

➢ Distribution of matrix and fracture



The heterogeneous fluid pressure due to the difference of permeability between matrix and fracture:

- ◆ High pressure: area away the fracture
- ◆ Medium pressure: the matrix area near the fracture
- ◆ Low pressure: area near the fracture



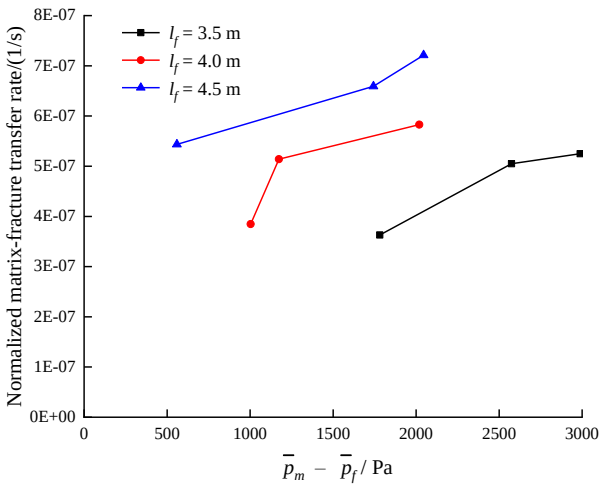
Pressure distribution of matrix and fracture

- ◆ Peaks and troughs appear in the matrix pressure curve along the flow direction due to the complexity of fracture geometry
- ◆ Inconsistent directions of matrix-fracture flow transfer because of the heterogeneous fluid pressure around the matrix

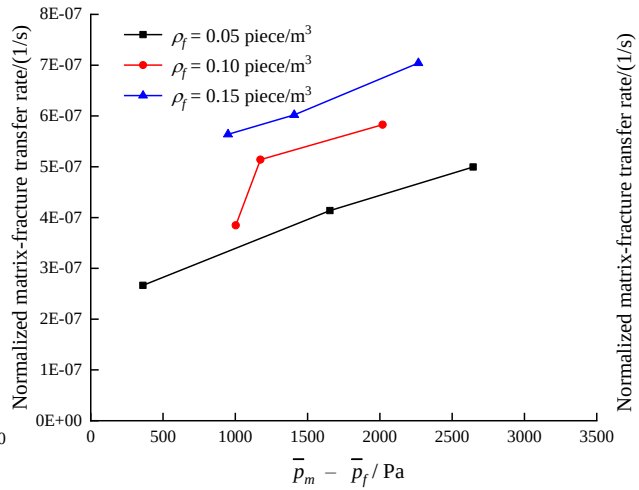
4. Effect of influencing factors

❖ Discussion of simulation results

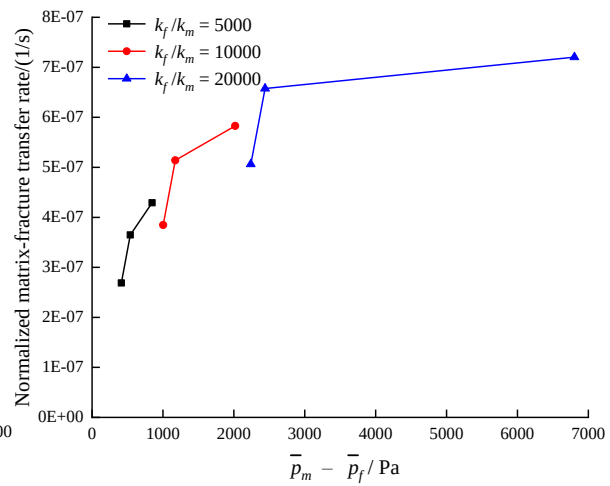
➢ Effect of influencing factors



Relations between matrix-fracture pressure difference and matrix-fracture flow transfer with different fracture trace lengths



Relations between matrix-fracture pressure difference and matrix-fracture flow transfer with different fracture density



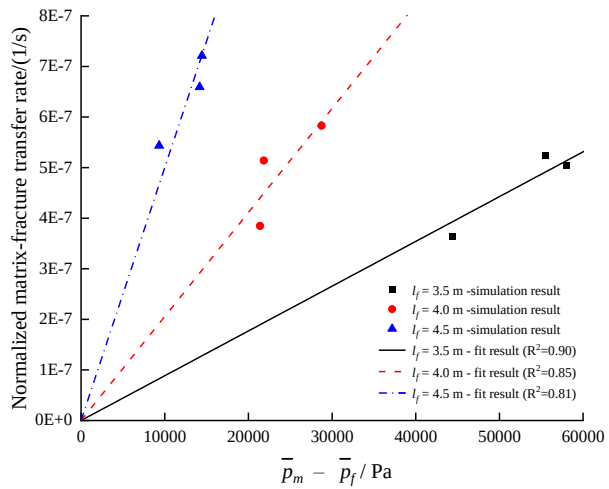
Relations between matrix-fracture pressure difference and matrix-fracture flow transfer with different fracture/matrix permeability ratio

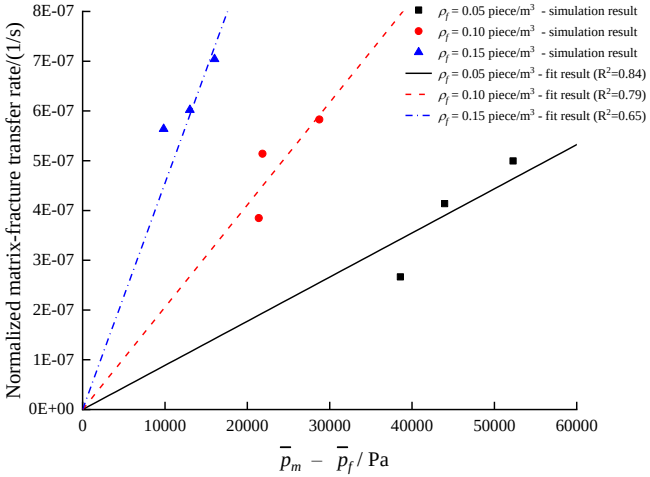
- ◆ The flow transfer rate presented a nonlinear increasing trend as the matrix-fracture pressure difference increased。
- ◆ The fracture aperture, trace length, and density have a positive effect on the flow transfer, and the FMPR has a negative effect on the flow transfer.

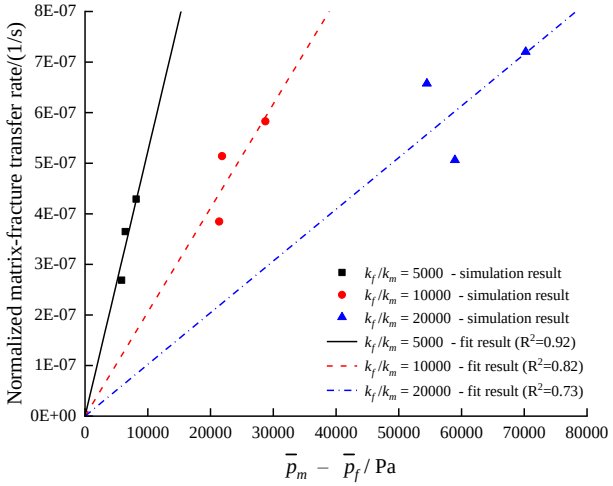
4. Effect of influencing factors

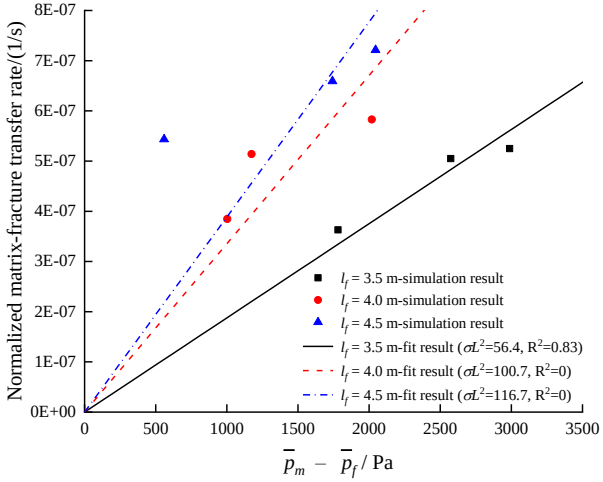
❖ Discussion of simulation results

➢ Verification of the flow transfer model

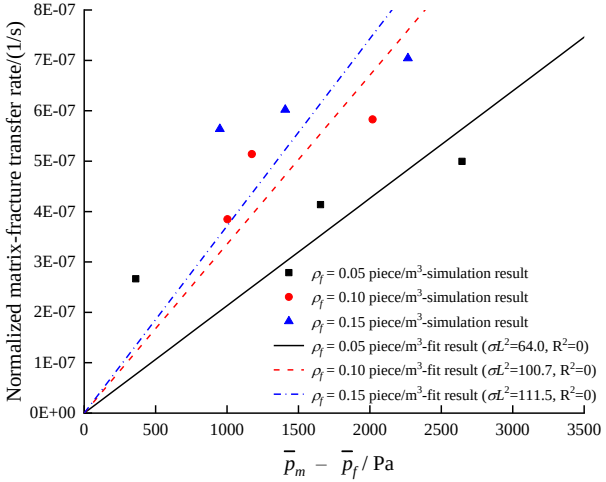




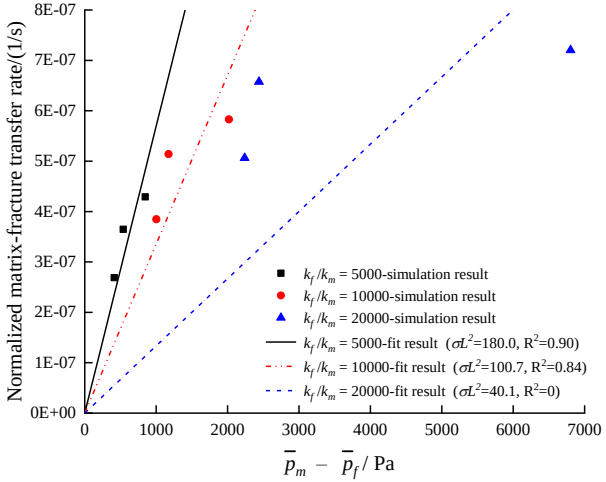




Influence of fracture trace length



Influence of fracture density



Influence of fracture/matrix permeability ratio

5. Concluding remarks

- Experiments of matrix-fracture flow transfer in fractured porous media were performed under different aperture and pressure difference between matrix and fracture. The experiments show that there is a strong nonlinear relationship between the matrix-fracture flow transfer term and flow rates.
- A generalized matrix-fracture flow transfer model for fractured porous media considering the influence of the stochastic fracture distribution on fluid flow was proposed. The matrix-fracture flow transfer term depends on the effective pressure difference between matrix and fracture.
- The influence of fracture trace length, density, and fracture/matrix permeability ratio on the matrix-fracture flow transfer term were investigated by simulation. The matrix-fracture flow transfer term increases with the increase of fracture trace length, density, and fracture/matrix permeability ratio, while the fracture pressure correction coefficient is opposite.

Thank you!

请各位专家批评指正