Sustainable Sand Management Control and Solutions - Balancing Performance, Costs, and Environment

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Squeezing Gravel-Pack in Multi-Layer Well with Sanding Cavities in Formation: Simulation, Optimization and Case Study

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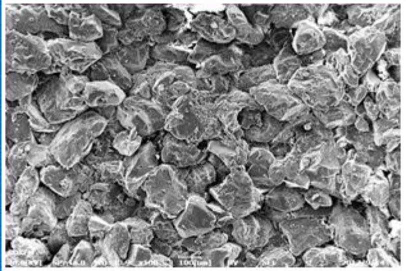
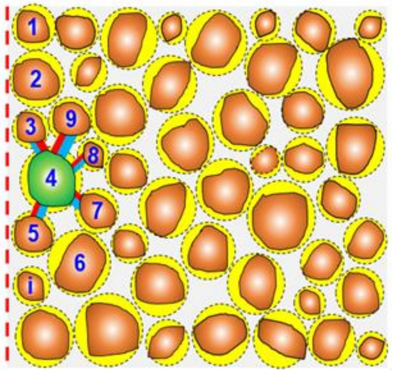
- Case Study

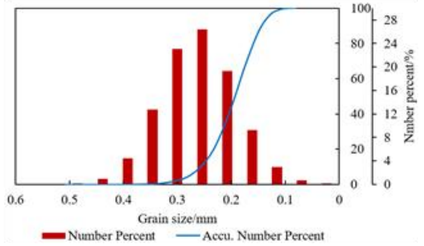
Simulation of sanding Cavities: Rationale

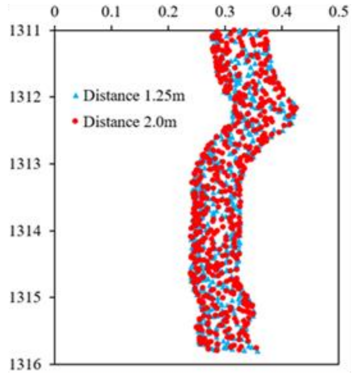
Microstructure modeling



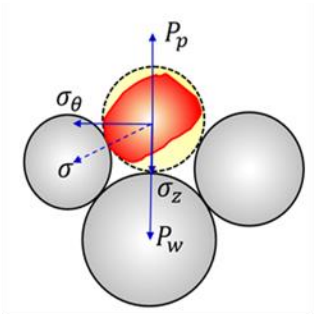


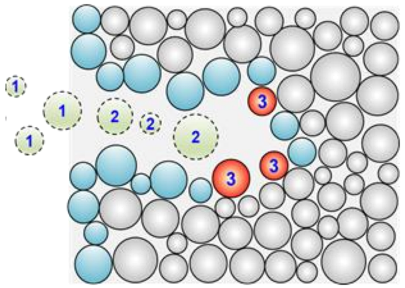
Non-homogeneous physical properties





Simulation of sand Prodcution





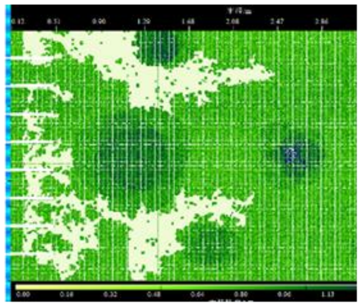
Sanding pattern management

$$K_{hmin} = K_{h0} \cdot (1 - X_s)$$

$$K_{hmax} = K_{h0} \cdot (1 + X_s)$$

$$f(i) = \frac{1}{\sqrt{2\pi} \cdot \sigma} \cdot exp\left[-\frac{\left(\frac{i}{N} - \mu\right)^2}{2\sigma^2} \right]$$

$$K_i = K_{hmin} + \frac{k_{hmax} - k_{hmin}}{f_{max} - f_{min}} \cdot [f(i) - f_{min}]$$



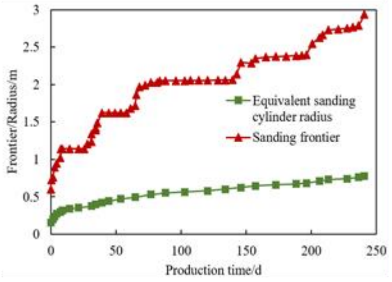
Sand production prediction

$$J_{xs} = \frac{L_{qs} \cdot S_{0a}}{V_{fa} \cdot U_f}$$

$$C_{s(i)} = \frac{Q_{s(i)}}{1000[Q_{g(i)} + Q_{l(i)}]}$$

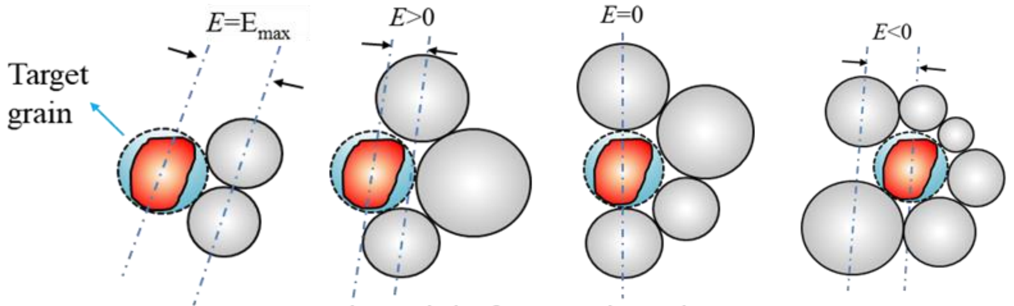
$$Q_{s(i)} = \frac{J_{xs} \cdot V_{f(i)} \cdot U_f}{s_{o(i)}}$$

$$Z_{(i)} = 0.5\frac{V_{f(i)}}{V_{fa}} + 0.5\frac{Q_{s(i)}}{Q_{sa}}$$

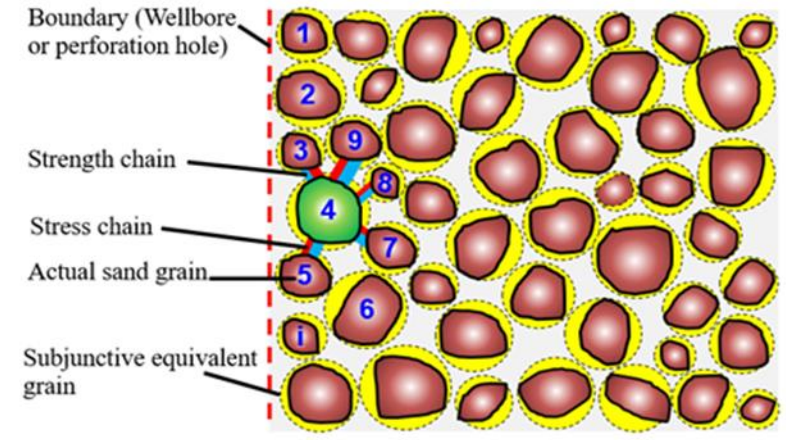


Simulation of sanding Cavities: Prediction method

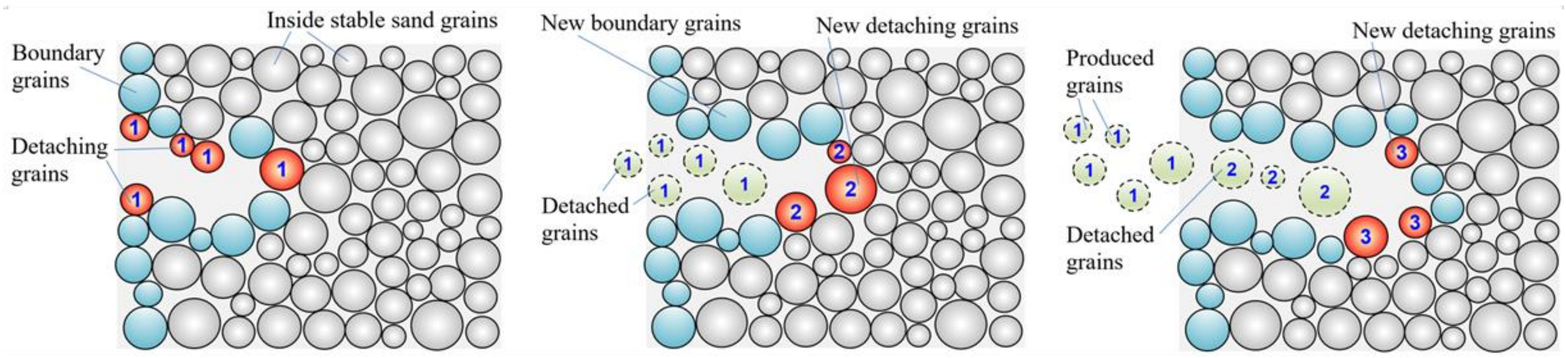
- Particles as objects (POM) microstructural model
- Particle size and shape distribution
- Physical heterogeneity characterization
- Random distribution of physical properties generally consistent with the physical manifestations



Structural model of grain detachment



POM

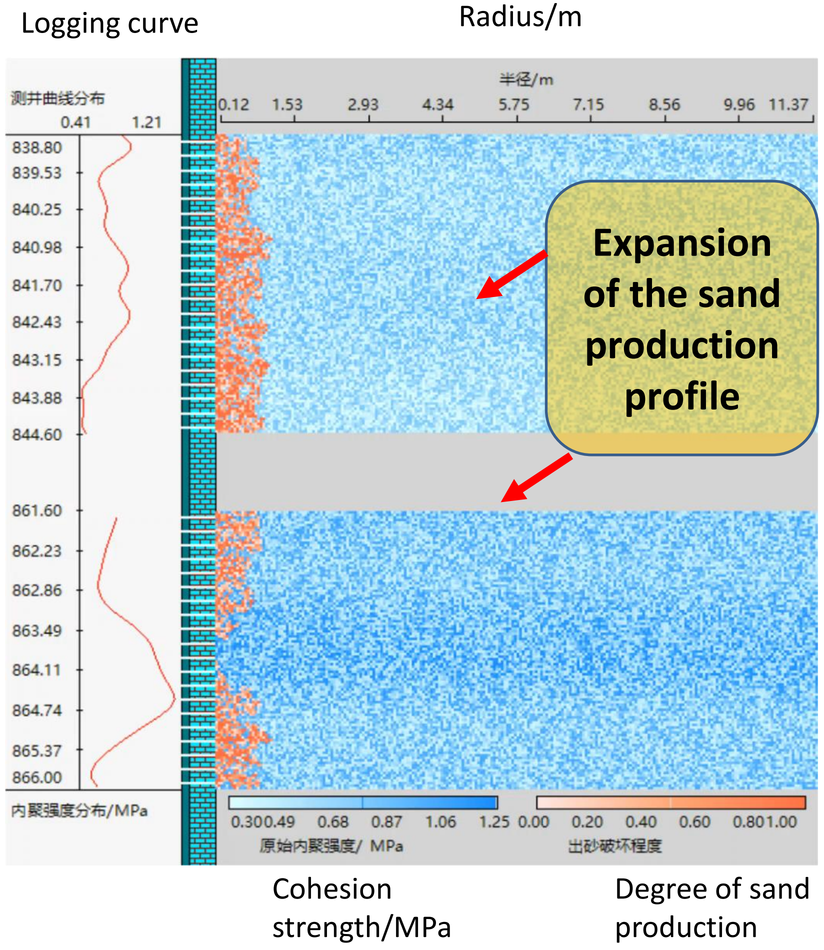


Diagrammatic sketch of principle of sand production simulation method

Simulation of sanding Cavities: Prediction method

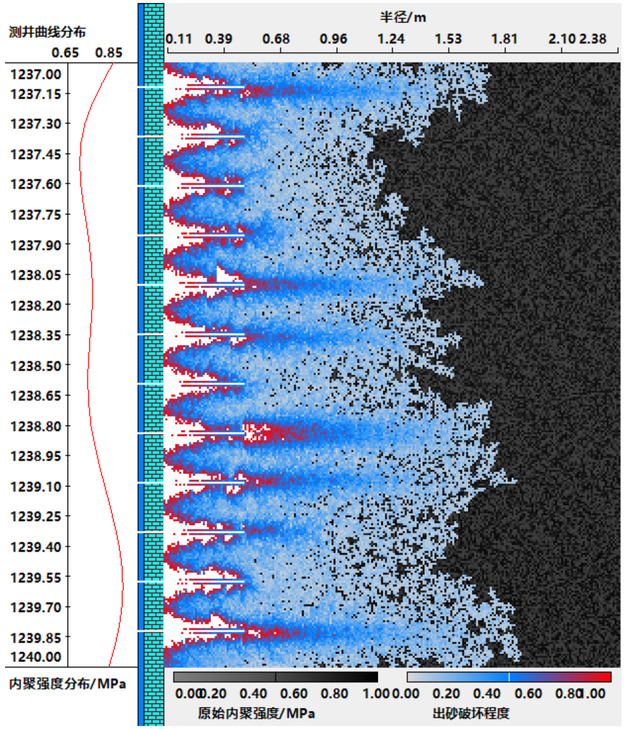
What can we obtain?

- Sand production Cavity volume
- Sanding Cavities pattern/profile
- The scope of sanding damage
- Sand damage degree
- Sand production degree index



Simulation of sanding Cavities: Simulation results

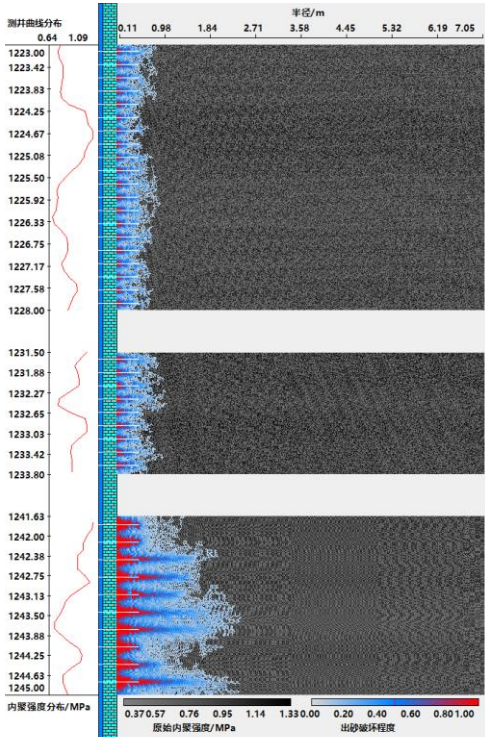
Simulation of a single-layer sand production cavities:



A single-layer sample

- The sand production form in the range of 0.4-1.0m
- The sanding damage range is 1.88 m, the average damage degree is 0.37, and the sanding degree index is 0.211.

Three layers of sand production cavities simulation:



A three-layer sample

- The sand production difference between layers is obvious.
- The sand production ranges of the three layers are 0.937 m, 1.068 m and 2.463 m, respectively.

Up to 8 layers can be simulated simultaneously

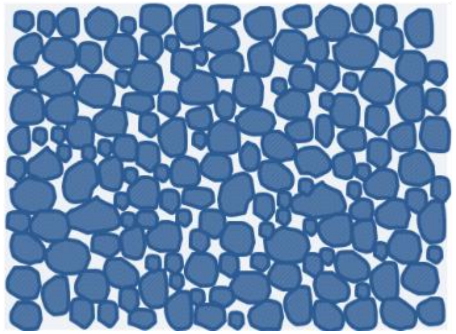
Simulation of sanding Cavities: Pattern management

Pattern A : Complete reservoir morphology, no sand pores and cavities.

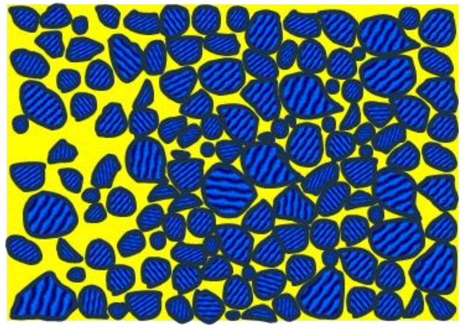
Pattern B : The formation has different degrees of sand deficit, but the skeleton structure is complete.

- **Pattern B1** : Pore liquefaction form, but the formation skeleton is complete.
- **Pattern B2 :** The formation skeleton was slightly damaged .
- **Pattern B3 :** Earthworm-like hole shape

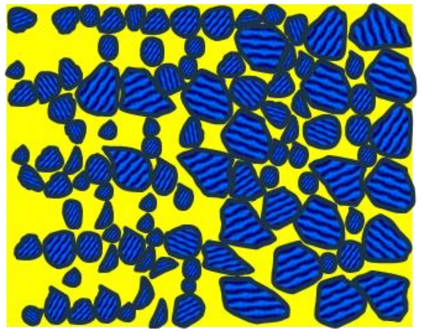
Pattern C : large hole form, formation sand production is serious.



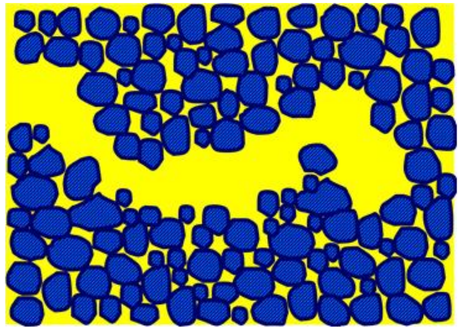
Pattern A



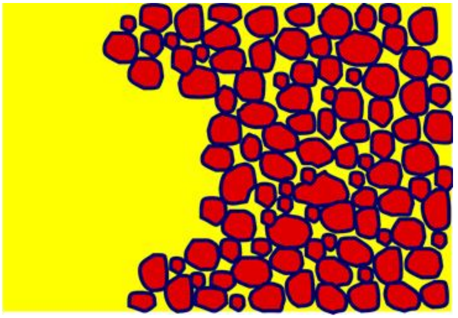
Pattern B1



Pattern B2



Pattern B3



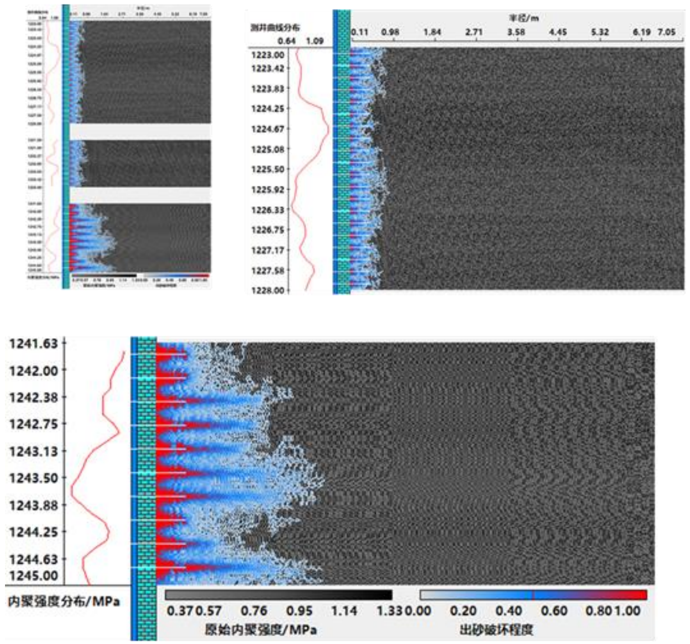
Pattern C

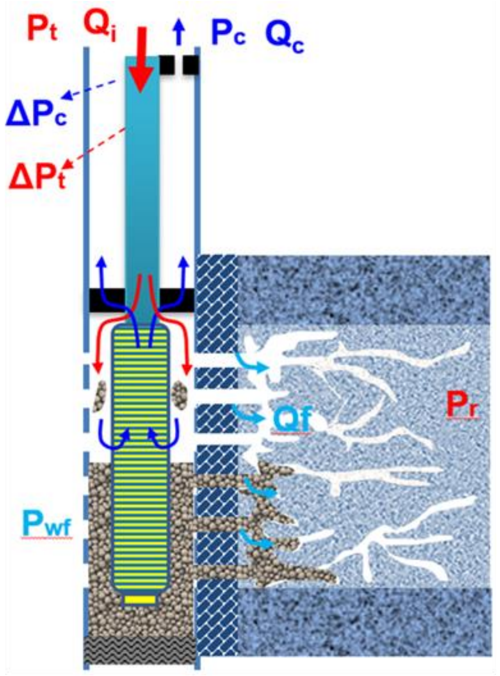
Squeezing Gravel-Pack in Multi-Layer Well: Rationale

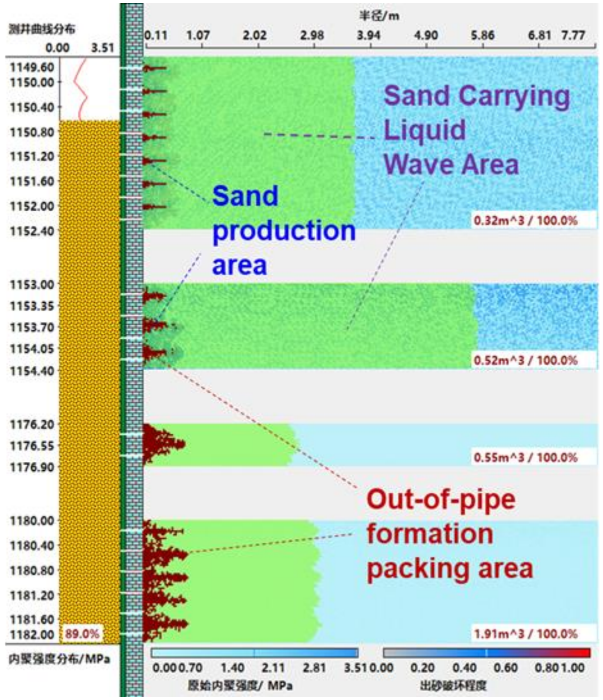
1. Description or prediction of sanding cavities

2. Squeezing Gravel-Pack Simulation in Multi-Layer Well

3. Optimization of packing parameters







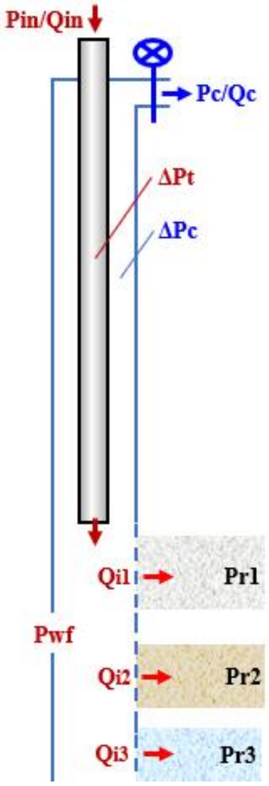
Squeezing Gravel-Pack in Multi-Layer Well: Models

- M1: Oil pipeline pumping friction model
- M2: Casing return flow friction model
- M3: Single-layer suction index model
- M4: Multi-layer flow balance model
- M5: Casing flow balance model
- M6: Sand discharge deficit filling model

All data models integrated into the software **Sandcontrol Office**, an integrated decision-making software platform for solids control.

Squeezing Gravel-Pack in Multi-Layer Well: Models

M1: Oil pipeline pumping friction model



- **Solid-liquid mortar physical property calculation model**

$$V_g = V_{gb}(1-\varphi_g) \qquad \rho_{gb} = \rho_g(1-\varphi_g) \qquad V_m = V_{gb}(1-\varphi_g) + V_l$$

$$C_g = \frac{R_g(1-\varphi_g)}{R_g(1-\varphi_g)+1} \qquad \rho_m = \frac{R_g(1-\varphi_g)\cdot\rho_g + \rho_l}{R_g(1-\varphi_g)+1}$$

- **Sand-carrying liquid and solid-liquid mortar pipe flow friction model**

$$\frac{dP}{dh} = \rho_m g \sin\theta + f_m \frac{\rho_m}{D}\frac{v_m^2}{2}$$

- **Modeling of orifice flow friction pressure drop**

$$(\Delta P_f)_{perf} = \alpha \frac{B\rho q_0^2}{d_0^4}\left(\frac{L_p}{L_{p0}}\right)$$ Unfilled perforation

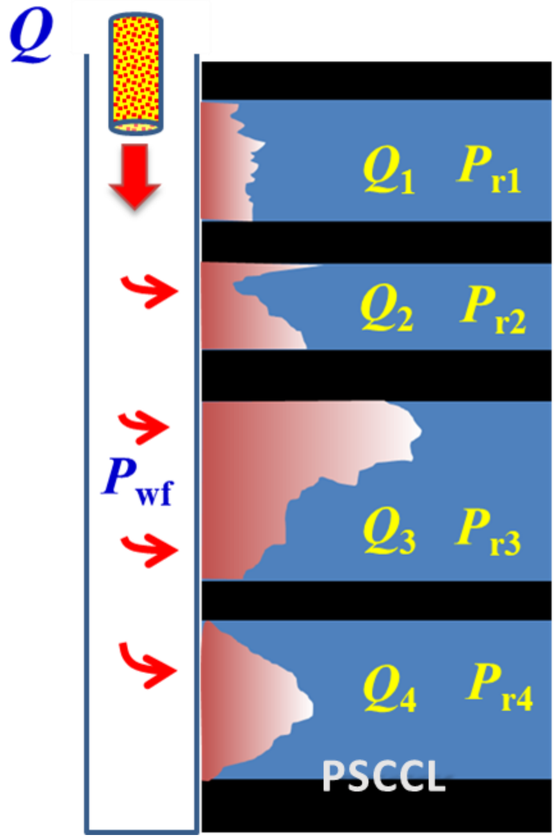
$$\Delta P = \alpha(q \cdot \frac{\mu B L_p}{\pi k_p h_p S_D r_p^2} + q^2 \cdot \frac{\beta_p \rho B^2 L_p}{\pi^2 h_p^2 S_D^2 r_p^4})$$ Filled perforation

- **Horizontal flow gravel deposition model**

$$v_c = 15 v_t \cdot \left[\frac{D_p \cdot v_t \cdot \rho_l}{u_l}\right]^{0.39} \cdot \left[\frac{d_g \cdot v_t \cdot \rho_l}{u_l}\right]^{-0.73} \cdot \left[\frac{\rho_g - \rho_l}{\rho_l}\right]^{0.17} \cdot [C_s]^{0.14}$$

Squeezing Gravel-Pack in Multi-Layer Well: Models

M4: Multi-layer flow model



Under the condition of given total injection displacement Q and bottom hole pressure P_{wf}, Injection ratio R_{qi} by layer

$$Q = A \cdot \sum_{i=1}^{m} k_i h_i (P_{wf} - P_{ri}) \qquad R_{qi} = \frac{k_i h_i (P_{wf} - P_{ri})}{\sum_{i=1}^{m} k_i h_i (P_{wf} - P_{ri})}$$

Considering the deficit of sand production, the comprehensive degree of the deficit of sand production is represented by the index B_i

Modified indicator B_i: $$B_a = \frac{\sum_{i=1}^{m} B_i}{m} \qquad B_{xi} = B_i - B_a$$

Injection ratio R_{qi}: $$R_{qi} = R_{qi} * 0.85 + B_{xi} * 0.15 \qquad \sum_{i=1}^{m} R_{qi} = 1.0$$

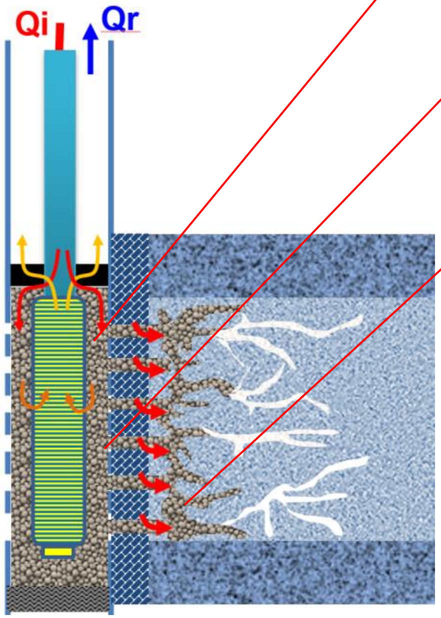
Actual injection volume per single layer: $\boldsymbol{Q_i = Q \cdot R_{qi}}$

Squeezing Gravel-Pack in Multi-Layer Well: Optimization

- **Optimization basis** : Physical properties of the target layer, degree of sand deficit, properties of the sand-carrying fluid, and characteristics of the packing material.
- **Optimization objectives** : Gravel packing volume, sand ratio, displacement, annulus pressure differential/shunt squeeze pressure differential, and pump injection procedure.
- **Optimization principle** : Ensure dense packing in the annulus, thorough packing of perforation tunnels, and effective packing of large-scale sand deficit cavities outside the perforation zone.

Squeezing Gravel-Pack in Multi-Layer Well: Optimization

Gravel-Pack Volume Design



a. Amount of gravel packed in the wellbore Vgi

$$V_{gi} = \frac{\pi}{4} d_{ci}^2 \cdot L_{kd} + \frac{\pi}{4}\left(d_{ci}^2 - d_{\mathrm{so}}^2\right) \cdot L_{\mathrm{scr}}$$

b. Perforation hole volume gravel amount Vgp

$$V_{gp} = \frac{\pi}{4} d_p^2 \cdot L_p \cdot h_p \cdot S_D$$

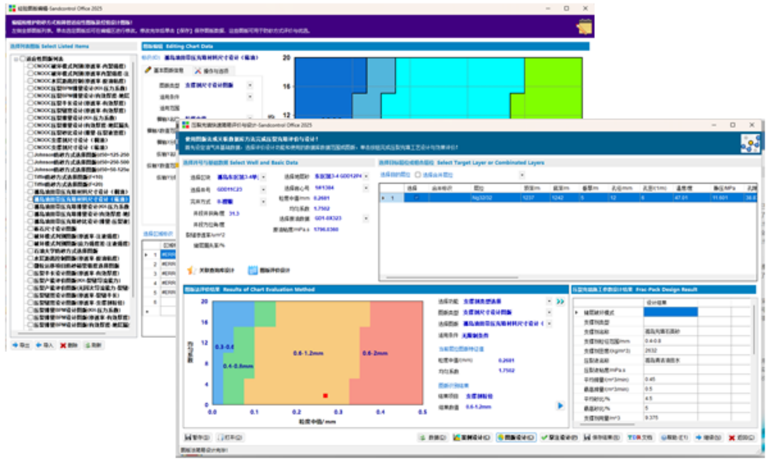
c. Amount of gravel packed in the formations outside the pipe Vgo：

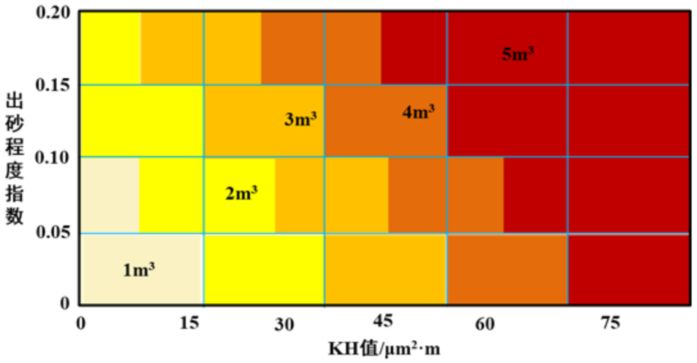
- **Optimization Principle： Based on the simulation results of the sand deficit pattern in the reservoir, the sand cavities volume was calculated**

Total gravel packed volume Vg $V_g = \left(V_{gi} + V_{gp} + V_{go}\right) \cdot \beta$

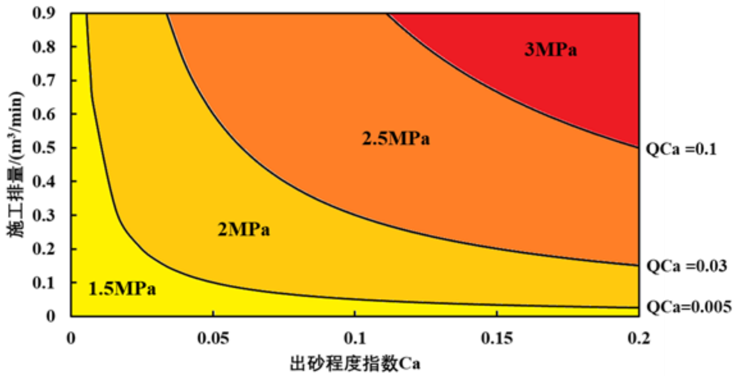
β—Actual construction preparation gravel volume surcharge factor, recommended 1.1-1.25

Squeezing Gravel-Pack in Multi-Layer Well: Optimization





Packing scale design (KH value - sand deficit volume)



Compact ring-packed casing pressurization design plate (sand degree index - displacement)

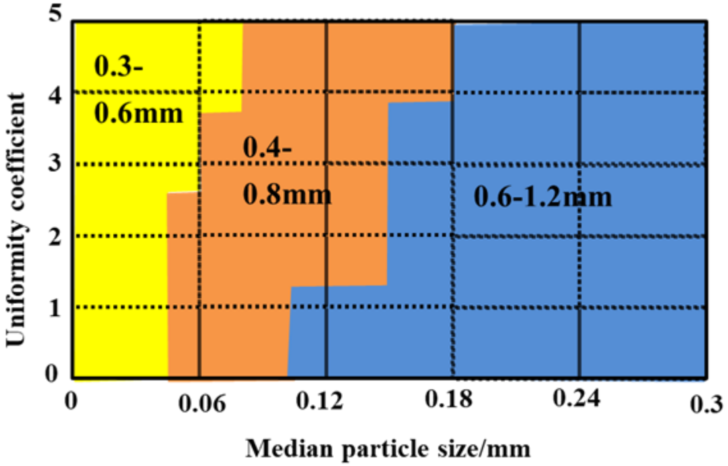
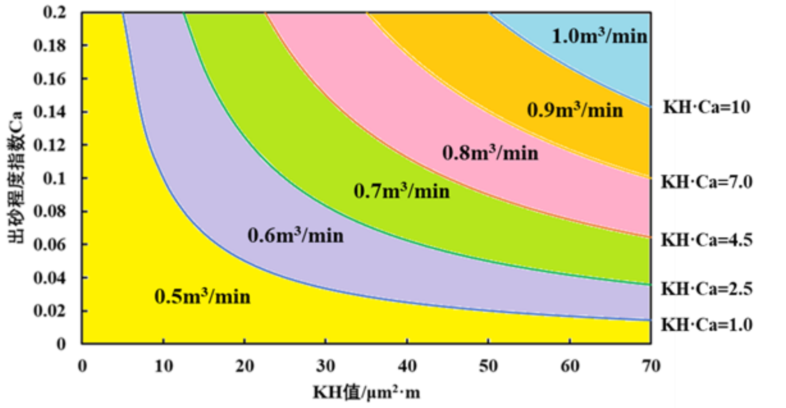
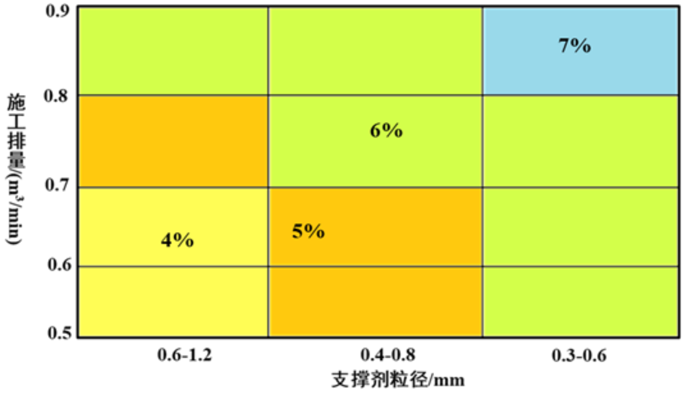


Plate for selection of packing material particle size



Packing Displacement Design Plate (KH Value - Degree of Sand Production Index Ca)

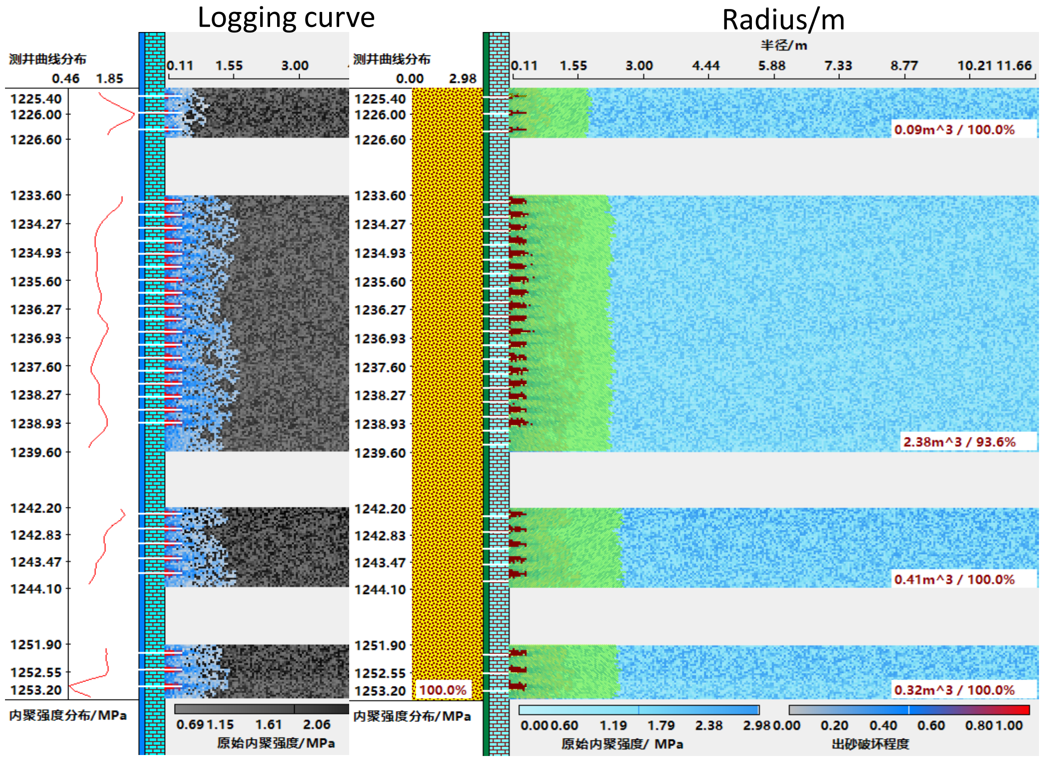


Construction Sand Ratio Design Plate (proppant grain size - construction displacement)

Squeezing Gravel-Pack in Multi-Layer Well: Case Study

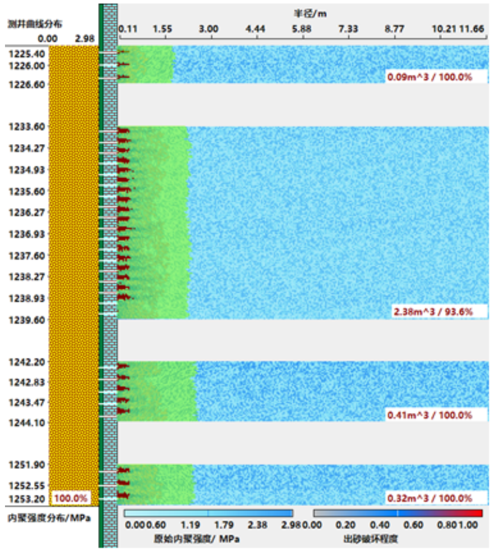
Well Completion Method	Perforation	Pressure-bearing annulus packing	
Perforation density/(1/m)	12.0	Perforation diameter/mm	12.0
Viscosity of liquid/mPa.s	1.050	Perforation length/mm	0.45
Packing material	Quartz sand	Material density/(kg/m^3)	1632
Particle size/mm	0.45 - 0.90	Squeezing Gravel-Pack amount /m^3	3.32

	Procedures	Liquid amount/ m^3	Sand ratio/%	amount of gravel/m^3	Sand carrying volume/ m^3	Displacement/(m^3/min)	Time /min	Maximum pump pressure/MPa
1	Cycle washing	3.00			3.00	0.70	4.29	23.82
2	Squeezing Gravel-Pack	33.20	5.0	1.66	34.28	0.70	48.97	23.82
3	Squeezing Gravel-Pack	23.71	7.0	1.66	24.79	0.70	35.42	23.82
4	Cyclic packing	24.60	5.0	1.23	25.40	0.70	36.29	23.82
5	Replacement	5.51			5.51	1.00	5.50	19.13

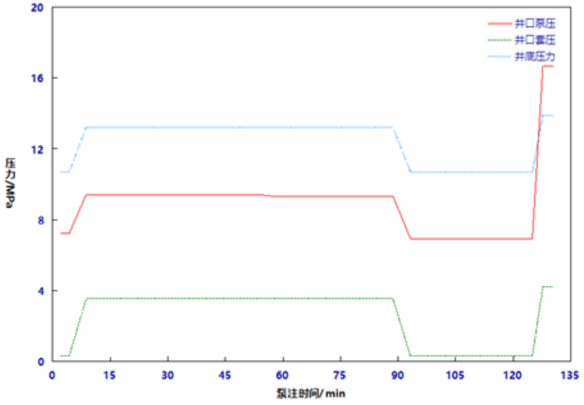


- According to the simulation results, the sand packing volume and packing rate in the four layers from top to bottom are 0.09m^3/100%, 2.38m^3/93.6%, 0.41m^3/100% and 0.32m^3/100%, respectively.

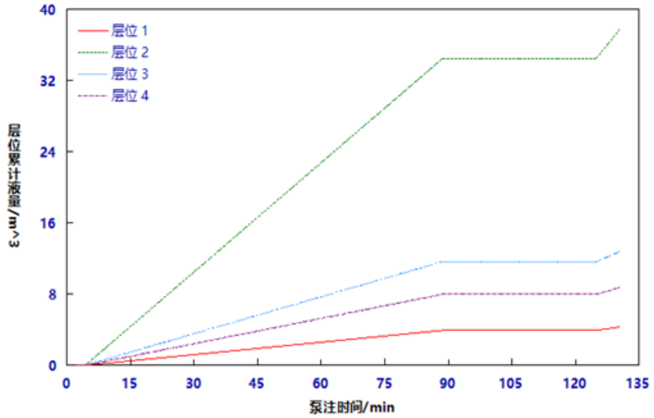
Squeezing Gravel-Pack in Multi-Layer Well: Case Study



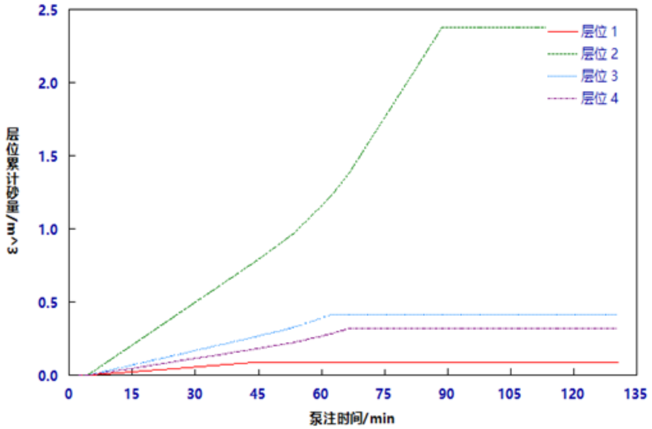
Pressure

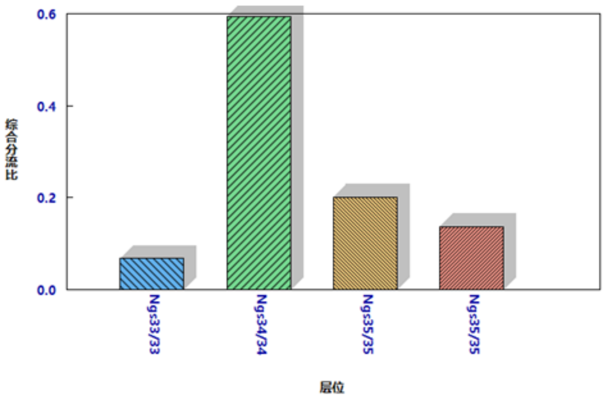


Liquid volume

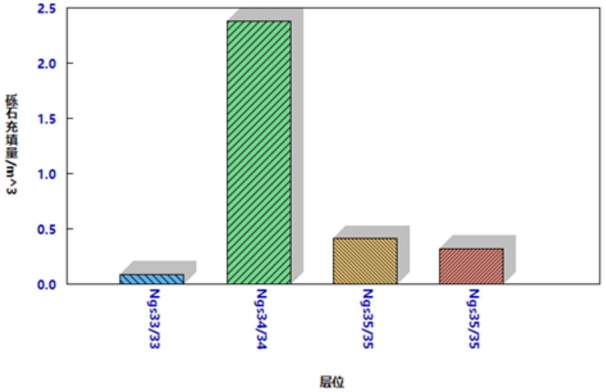


Sand volume

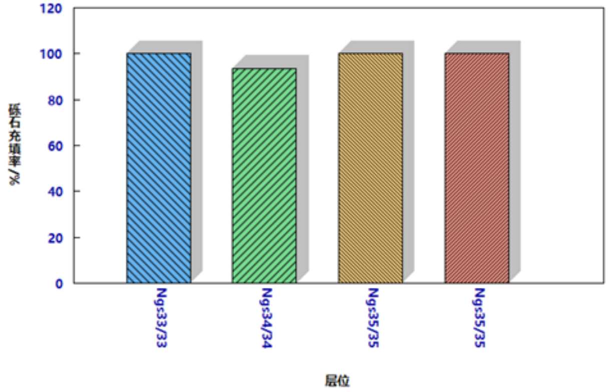




Bypass ratio



Packing volume



Packing rate

Conclusion

- **Accurate Sand Production Prediction**

The microstructural model and multi-layer simulation provide reliable predictions of sanding cavities and their patterns, guiding effective sand management.

- **Optimized Squeezing Gravel-Pack Strategies**

By integrating multiple models, our approach allows precise optimization of packing parameters, ensuring enhanced performance in complex multi-layer wells.

- **Case Study Results**

The simulation-driven packing design resulted in high efficiency, with over 93% packing rates across critical layers, demonstrating the model's practical effectiveness.

- **Sustainable and Cost-Effective**

This comprehensive method balances performance, and environmental impact, offering a robust solution for sustainable sand control management.

Thanks!

Welcome any communication and cooperation!

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