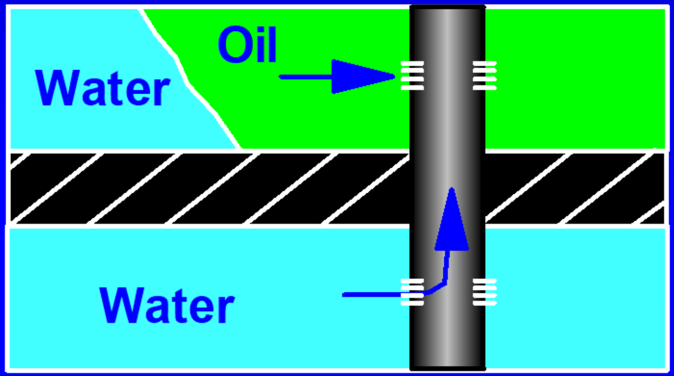
A STRATEGY FOR ATTACKING EXCESS WATER PRODUCTION

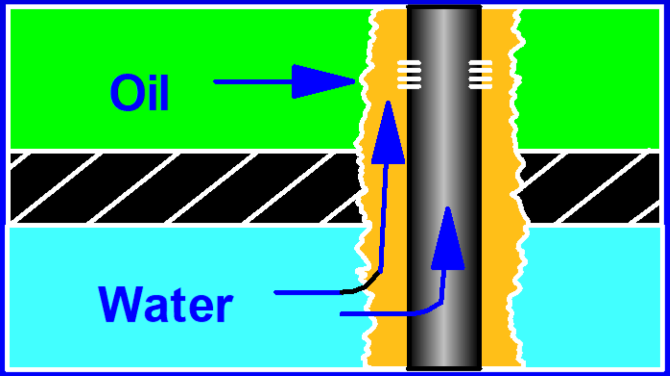
SPEPF (August 2003) pp. 158-169

CAUSES OF EXCESS WATER PRODUCTION

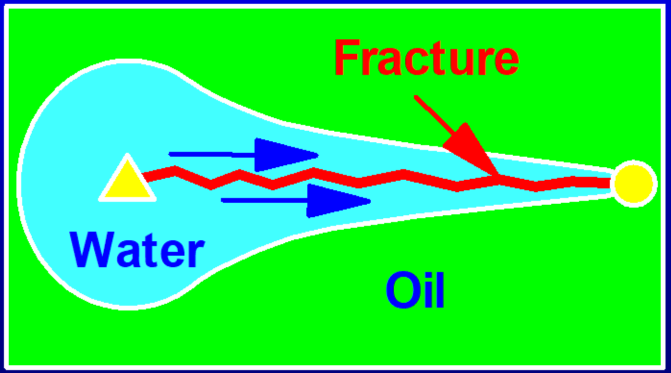
Open Water Zone



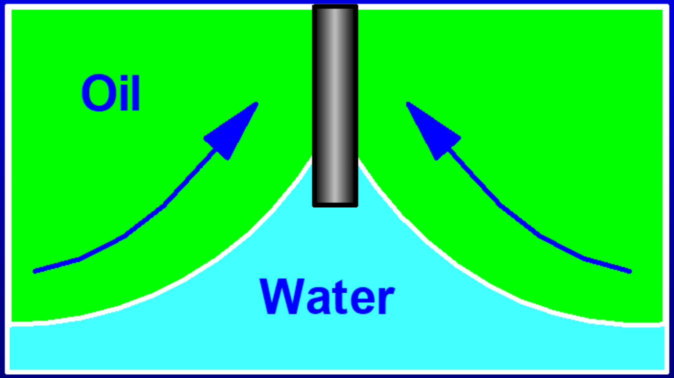
Flow Behind Pipe and Casing Leaks



Channeling from Injectors



Coning or Cusping



WATER CONTROL METHODS

- Cement, sand plugs, calcium carbonate.
- Packers, bridge plugs, mechanical patches.
- Pattern flow control.
- In fill drilling/well abandonment.
- Horizontal wells.
- Gels.
- Polymer floods.
- Resins.
- Foams, emulsions, particulates, precipitates, microorganisms.

PROBLEM

Operators often do not adequately diagnose the cause of their water production problems.

WHY NOT?

1. **Diagnosis requires money and time,**
2. **Uncertainty about which methods are cost-effective for diagnosing specific problems,**
3. **Preconception that only one type of problem exists or that one method will solve all types of problems,**
4. **Some companies encourage a belief that they have "magic-bullet" solutions.**

A STRATEGY FOR ATTACKING EXCESS WATER PRODUCTION

1. Consider and eliminate the easiest problems first.
2. Start by using information that you already have.

Excess Water Production Problems and Treatment Categories

(Categories are listed in increasing order of treatment difficulty)

Category A: "Conventional" Treatments Normally Are an Effective Choice

1. Casing leaks without flow restrictions.
2. Flow behind pipe without flow restrictions.
3. Unfractured wells (injectors or producers) with effective crossflow barriers.

Category B: Treatments with Gelants Normally Are an Effective Choice

4. Casing leaks with flow restrictions.
5. Flow behind pipe with flow restrictions.
6. "Two-dimensional coning" through a hydraulic fracture from an aquifer.
7. Natural fracture system leading to an aquifer.

Category C: Treatments with Preformed Gels Are an Effective Choice

8. Faults or fractures crossing a deviated or horizontal well.
9. Single fracture causing channeling between wells.
10. Natural fracture system allowing channeling between wells.

Category D: Difficult Problems Where Gel Treatments Should Not Be Used

11. Three-dimensional coning.
12. Cusping.
13. Channeling through strata (no fractures), with crossflow.

WHAT DIAGNOSTIC TOOLS SHOULD BE USED?

1. Production history, WOR values, GOR values
2. Pattern recovery factors, zonal recovery factors
3. Pattern throughput values (bubble maps)
4. Injection profiles, production profiles
5. Zonal saturation determinations (from logs, cores, etc.)
6. Injectivities, productivites (rate/pressure), step rate tests
7. Casing/tubing integrity tests (leak tests)
8. Temperature surveys, noise logs
9. Cement bond logs
10. Televiewers, FMI logs
11. Interwell transit times, water/hydrocarbon composition
12. Mud losses & bit drops while drilling
13. Workover & stimulation responses, previous treatments
14. Pressure transient analysis, Inter-zone pressure tests
15. Geological analysis, seismic methods, tilt meters
16. Simulation, numerical, analytical methods
17. Other

DIAGNOSTICS

We have A LOT of diagnostic methods available.

We need a strategy to decide which methods should be examined/applied first.

Possible approaches:

1. **Use whatever tool is currently trendy and being pushed the hardest by my favorite service company.**
2. **Use the tools that have been popular in the past for this field.**
3. **Use a strategy that is focused finding the cause of channeling and/or excess water production.**

Strategy:

1. **Look for the easiest problems first.**
2. **Start by using information that you already have.**

KEY QUESTIONS IN OUR APPROACH

1. Does a problem really exist?
2. Does the problem occur right at the wellbore (like casing leaks or flow behind pipe) or does it occur out beyond the wellbore?
3. If the problem occurs out beyond the wellbore, are fractures or fracture-like features the main cause of the problem?
4. If the problem occurs out beyond the wellbore and fractures are not the cause of the problem, can crossflow occur between the dominant water zones and the dominant hydrocarbon zones?

Respect basic physical and engineering principles.
Stay away from black magic.

DOES A PROBLEM REALLY EXIST?

- Are significant volumes of mobile hydrocarbon present?
- Are recovery factors and/or WOR values much greater than neighboring wells or patterns?
- Are recovery values much less than expected after considering existing drive mechanism, existing stratification, structural position of the wells, injection fluid throughput, and existing mobility ratio?

FIRST SET OF DIAGNOSTIC TESTS

Recovery factor in view of:

- **Producing water/oil ratio, GOR.**
- **Neighboring wells and patterns.**
- **Drive mechanism.**
- **Reservoir stratification.**
- **Structural position.**
- **Injection fluid throughput.**
- **Water/oil mobility ratio.**

WOR DIAGNOSTIC PLOTS

WOR vs. time can be very valuable in determining:

1. **When the problem developed,**
2. **The severity of the problem,**
3. **What the problem is, IF VIEWED ALONG WITH OTHER INFORMATION.**

BUT WOR or WOR derivative plots CANNOT by themselves distinguish between channeling and coning. See Chapter 2 of our 1997 Annual Report

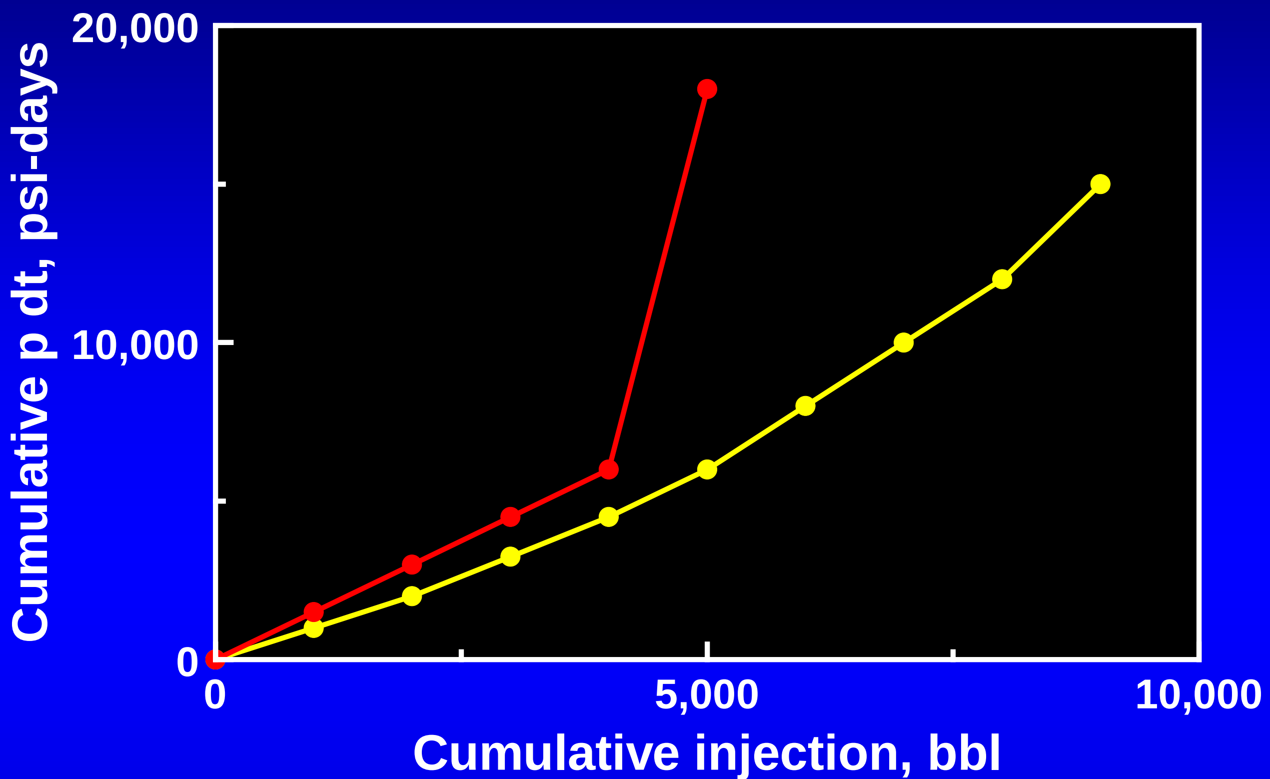
Distinguishing between matrix and fracture problems is much more important than distinguishing between channeling and coning.

HALL PLOTS

- provide a useful indication of the rate of pressure increase,
- indicate when gelant injection must be stopped because of pressure limitations,
- do not indicate the selectivity of gel placement,
- do not indicate whether a treatment was sized properly.

Reference: DOE/BC/14880-5, pp. 73-80.

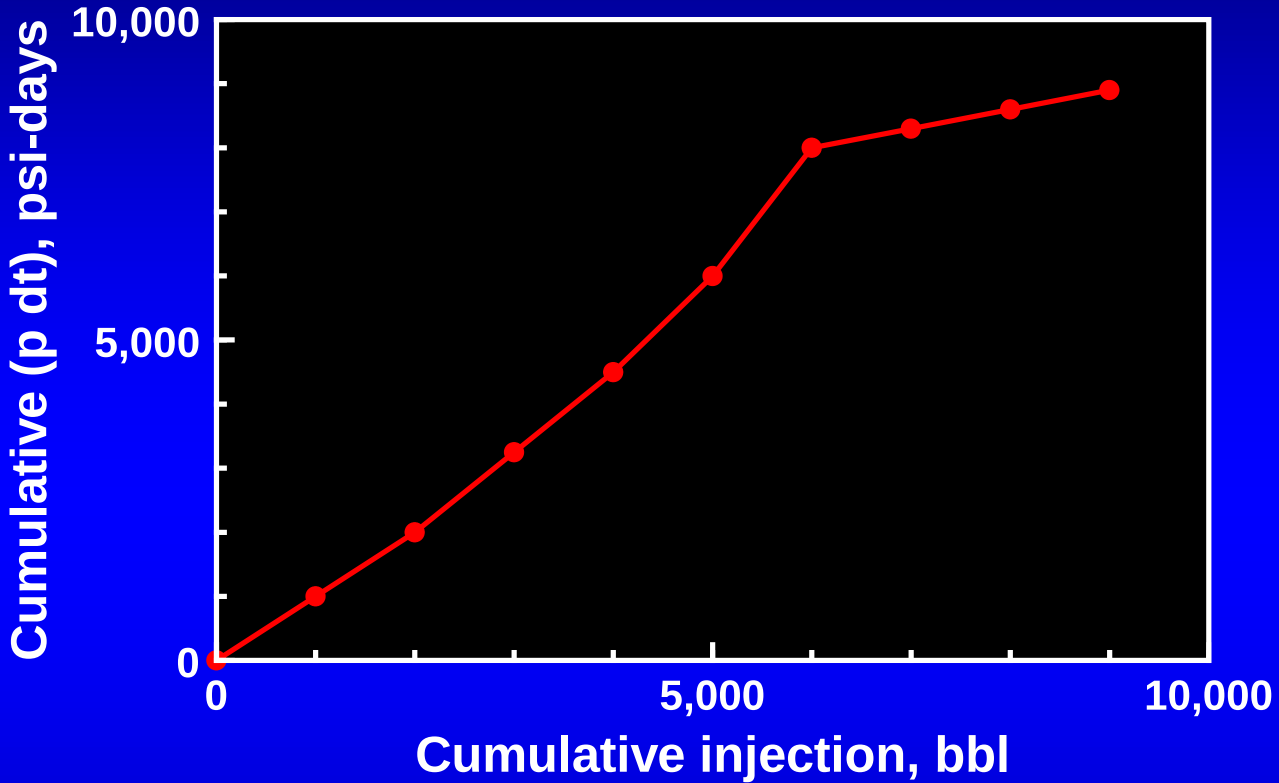
HALL PLOTS FOR WELLS WITH RADIAL FLOW



An increasing slope could result from:

- plugging the high-k zones more than the low-k zones,
- plugging the low-k zones more than the high-k zones, or
- plugging all zones to the same extent (most likely possibility).

HALL PLOTS FOR FRACTURED WELLS



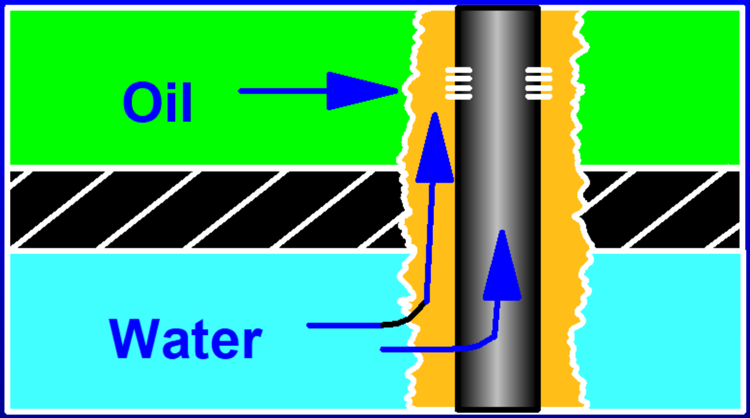
A decreasing slope could result from:

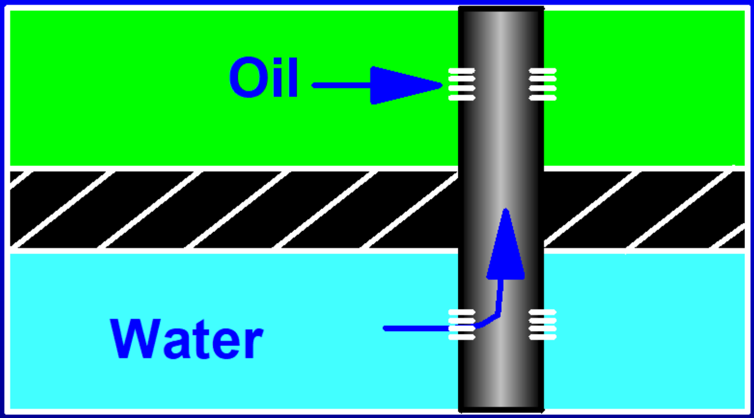
- opening or fracturing into previously unswept zones,
- re-opening a fracture that the gel had recently sealed,
- opening a fracture that cuts through all zones.

CATEGORY A: EASIEST PROBLEMS

“Conventional” Treatments Normally Are an Effective Choice

1. **Casing leaks without flow restrictions (moderate to large holes).**
2. **Flow behind pipe without flow restrictions (typically no primary cement).**
3. **Unfractured wells (injectors or producers) with effective barriers to crossflow.**





SECOND SET OF DIAGNOSTIC TESTS

Does the problem occur right at the wellbore?

Is the problem a leak or flow behind pipe?

- **Leak tests/casing integrity tests**
- **Temperature surveys**
- **Radio-tracer flow logs**
- **Spinner surveys**
- **Cement bond logs**
- **Borehole televiewers**
- **Noise logs**

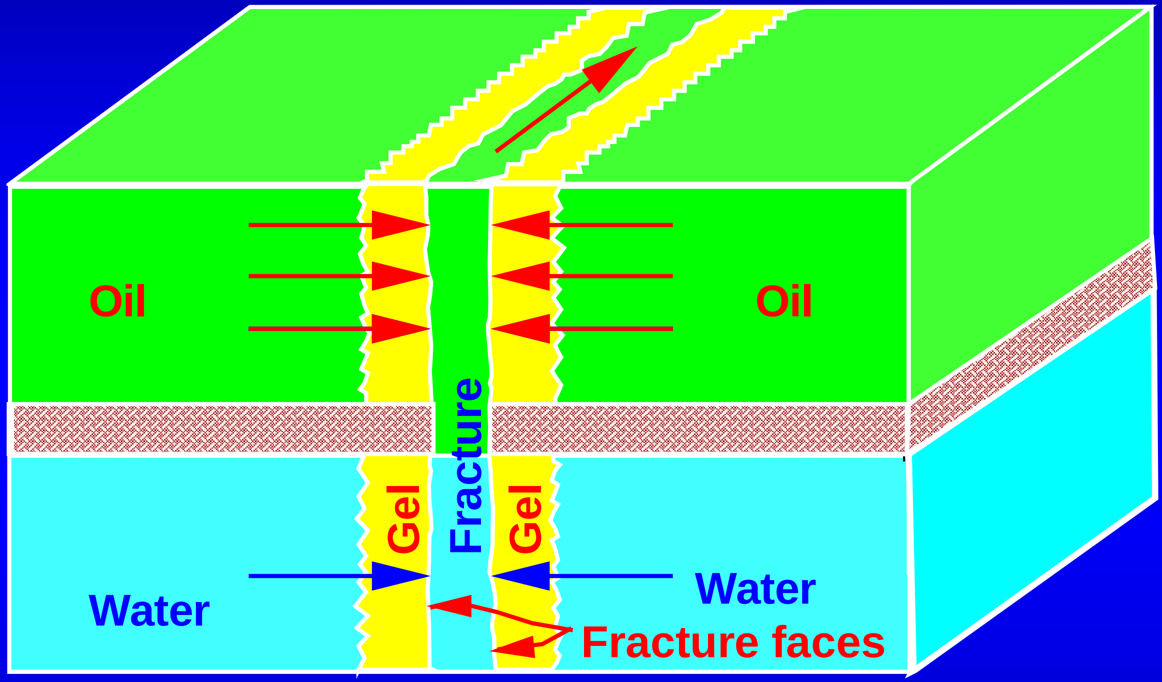
CATEGORY B:

INTERMEDIATE DIFFICULTY

Treatments with GELANTS Normally Are an Effective Choice

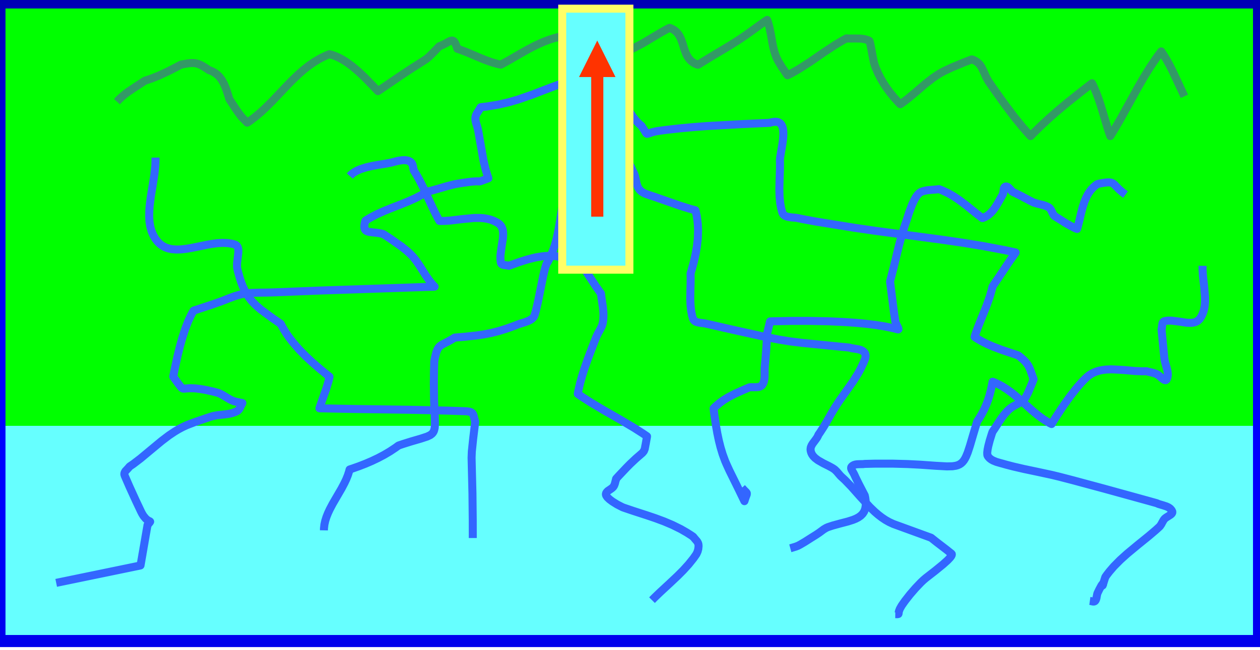
4. Casing leaks with flow restrictions (pinhole leaks).
5. Flow behind pipe with flow restrictions (narrow channels).
6. “Two-dimensional coning” through a hydraulic fracture from an aquifer.
7. Natural fracture system leading to an aquifer.

Problem 6: "Two-dimensional coning" through a hydraulic fracture from an aquifer.



- Need a gel that reduces k_w much more than k_o or k_{gas}.

Problem 7:
Natural fracture system leading to an aquifer.

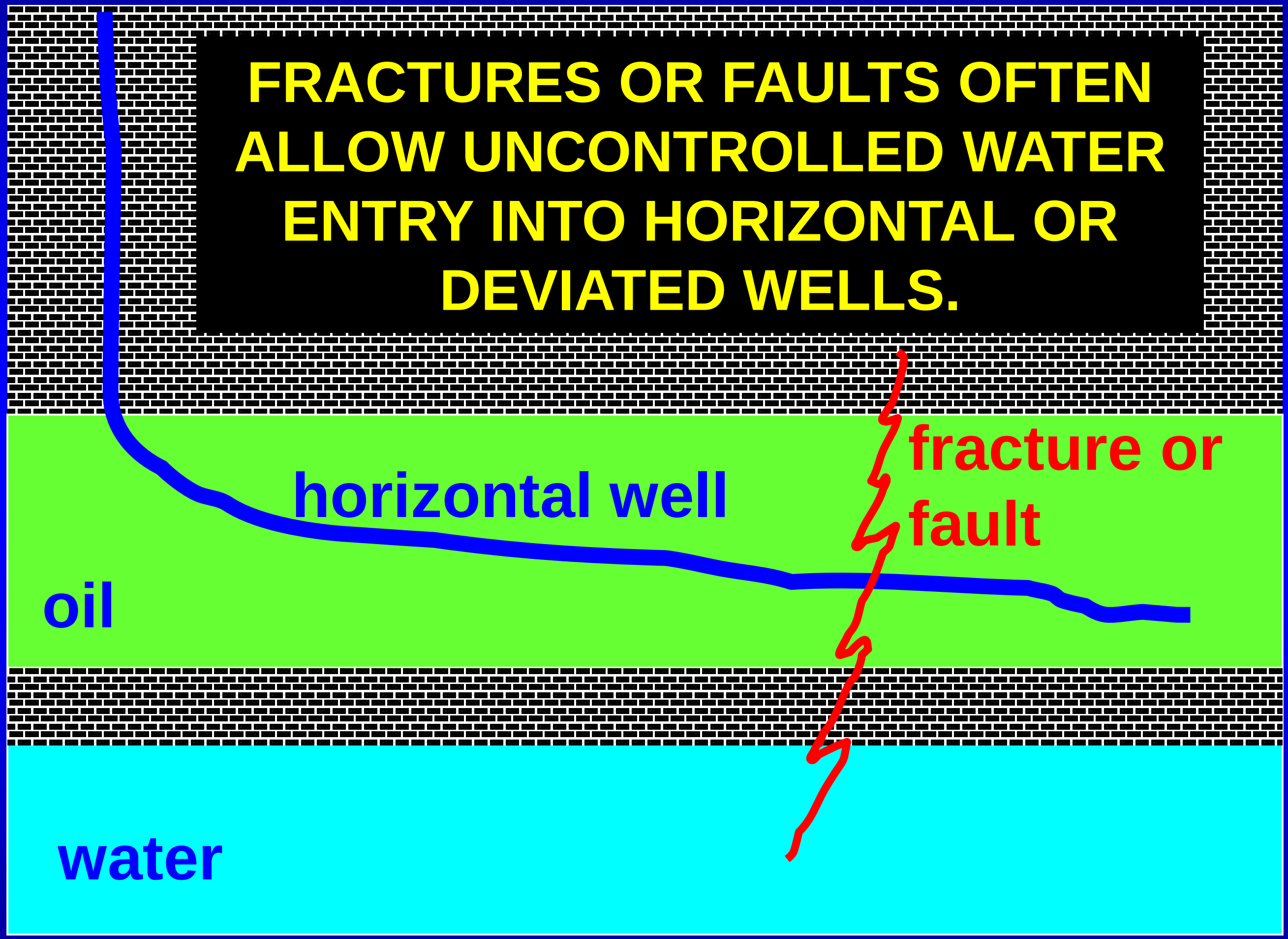


- Many successful gelant treatments applied in dolomite formations.
- Treatment effects were usually temporary.
- Recent, longer lasting successes seen with preformed gels.

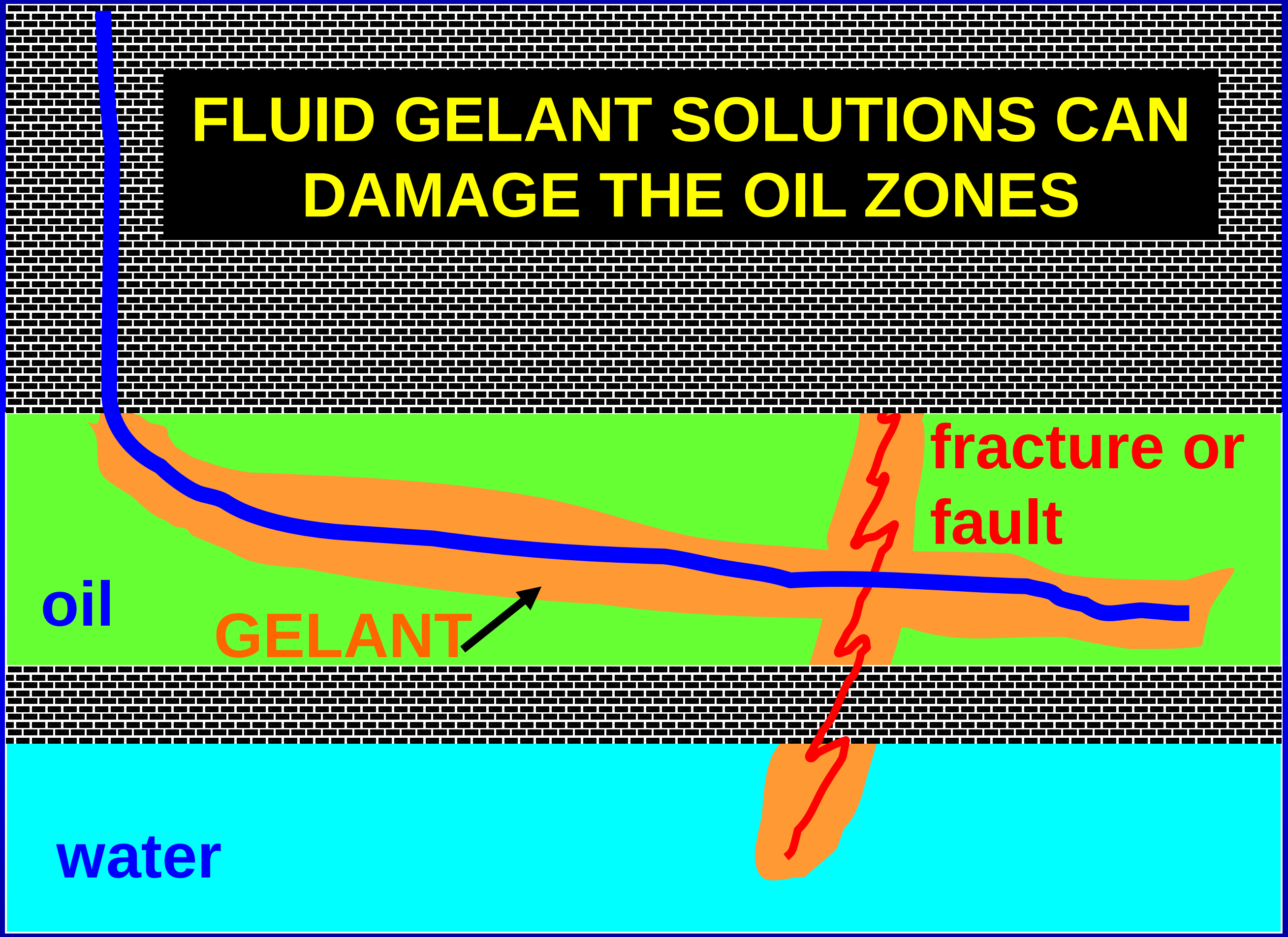
CATEGORY C:
INTERMEDIATE DIFFICULTY
Treatments with PREFORMED GELS Are an Effective Choice

8. Faults or fractures crossing a deviated or horizontal well.
9. Single fracture causing channeling between wells.
10. Natural fracture system allowing channeling between wells.

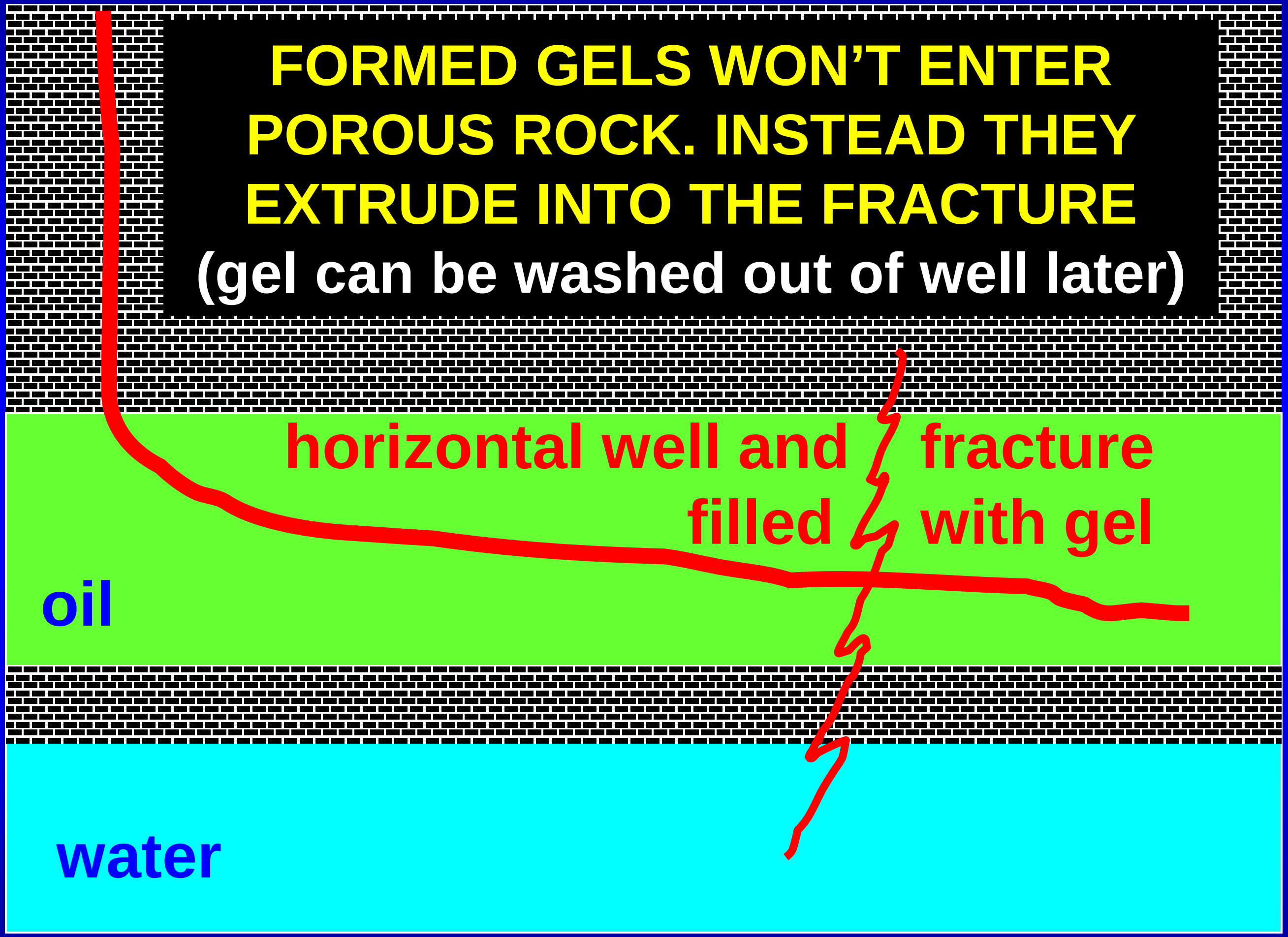
Problem 8


FRACTURES OR FAULTS OFTEN ALLOW UNCONTROLLED WATER ENTRY INTO HORIZONTAL OR DEVIATED WELLS.
horizontal well
fracture or fault
oil
water

Problem 8


FLUID GELANT SOLUTIONS CAN DAMAGE THE OIL ZONES
fracture or fault
oil
GELANT
water

Problem 8: SPE 65527



THIRD SET OF DIAGNOSTIC TESTS

HELPFUL INITIAL INDICATORS OF FRACTURES

- **Well history (intentional stimulation).**
- **Injectivity or productivity much higher than expected from Darcy’s law for radial flow.**
- **Results from step-rate tests.**

- **Speed of water breakthrough or other tracer.**

- **Fluid loss during drilling.**
- **Pulse test responses, or pumper observations.**

- **FMI logs**
- **Seismic**

Does my well have a linear-flow problem?
(e.g., a fracture)

Injectivity or productivity data often provides a low-cost method for diagnosis.

Radial (matrix) flow probable:

$$q/\Delta p \le (\Sigma\ k\ h)/[141.2\ \mu\ \ln\ (r_e\ /\ r_w)]$$

Linear (fracture-like) flow probable:

$$q/\Delta p >> (\Sigma\ k\ h)/[141.2\ \mu\ \ln\ (r_e\ /\ r_w)]$$

ESTIMATING FRACTURE CONDUCTIVITY FROM INJECTIVITY OR PRODUCTIVITY DATA

Assume:

- Vertical well with a vertical fracture
- If multiple fractures are present, the widest fracture dominates flow.
- The fracture has a much greater flow capacity than the matrix.
- The fracture has two wings.

$$q_{total} = q_{matrix} + q_{fracture} = (\Delta p\ h_f / \mu)\ [k_m / \ln(r_e/r_w) + 2k_f w_f / L_f]$$

$$k_f w_f = \{[q_{total}\ \mu/(\Delta p\ h_f)] - [k_m/\ln(r_e/r_w)]\}\ L_f /2$$

RELATION BETWEEN FRACTURE WIDTH, PERMEABILITY, AND CONDUCTIVITY

$k_f\ w_f$ (darcy-ft) = $1.13\text{x}10^{-5}\ (k_f)^{1.5}$, where k_f is in darcys.

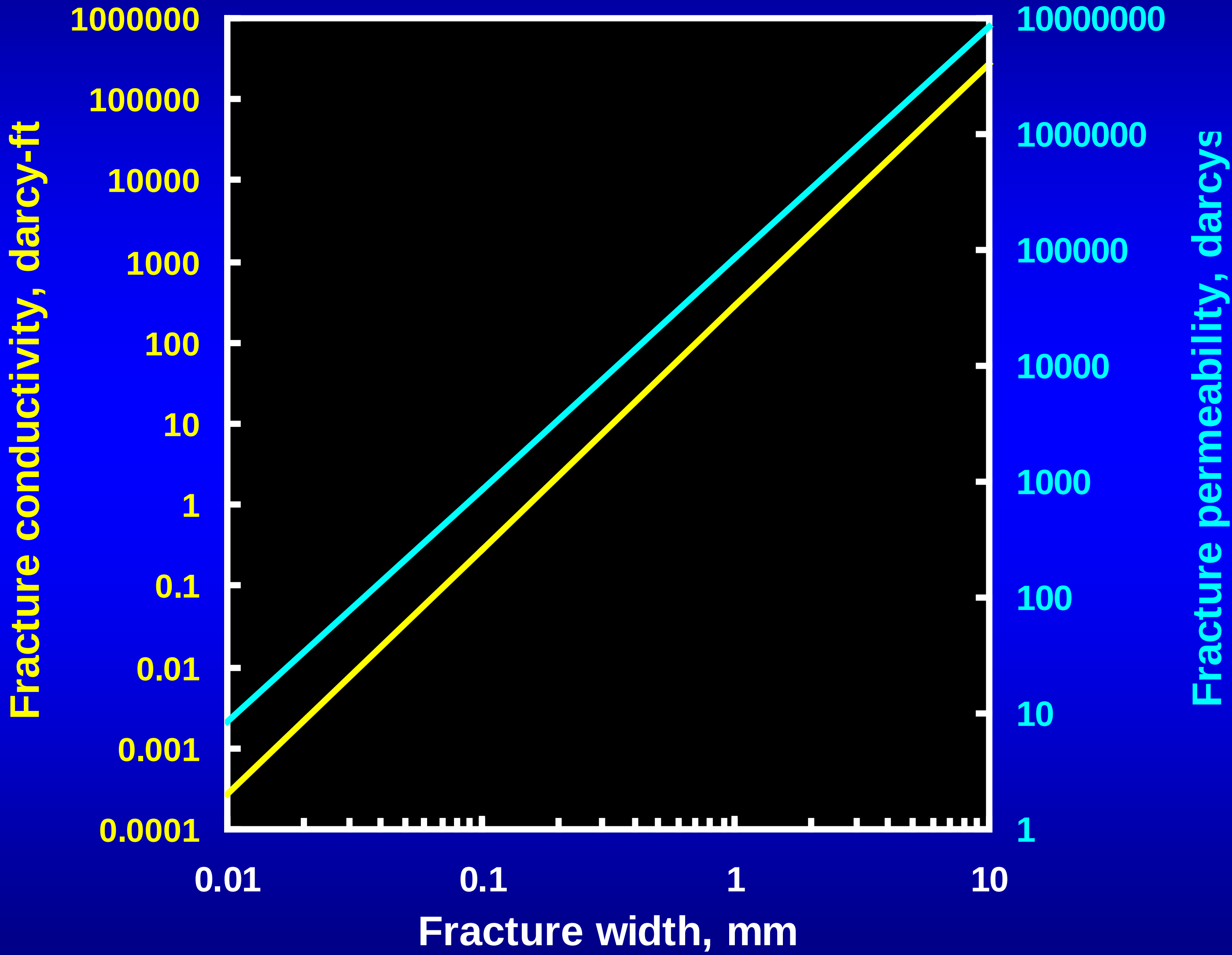
$k_f\ w_f$ (darcy-cm) = $3.44\text{x}10^{-4}\ (k_f)^{1.5}$, where k_f is in darcys.

w_f (ft) = $5.03\text{x}10^{-4}\ (k_f w_f)^{1/3}$, where $k_f w_f$ is in darcy-ft.

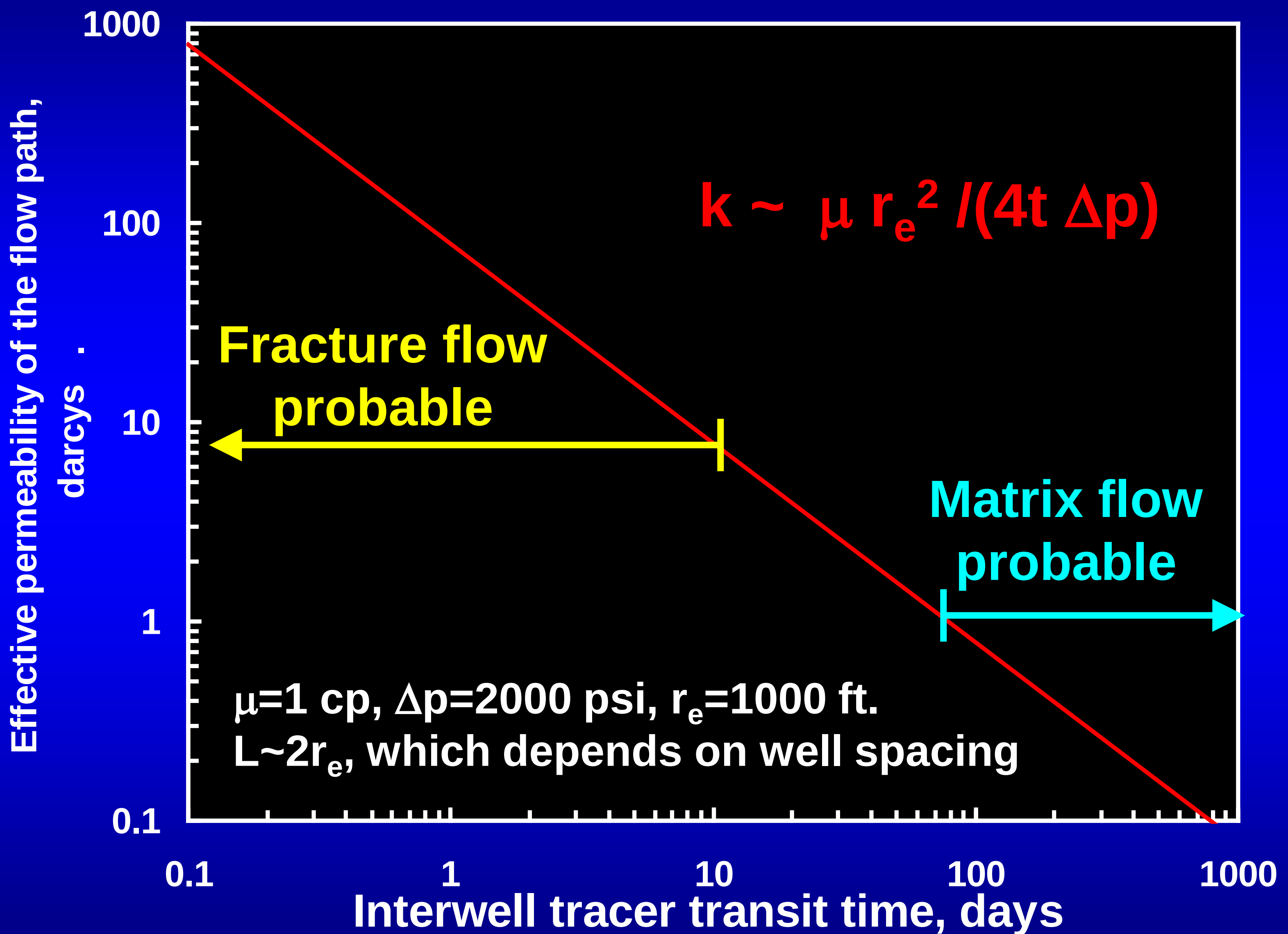
w_f (mm) = $0.153\ (k_f w_f)^{1/3}$, where $k_f w_f$ is in darcy-ft.

w_f (mm) = $3.44\text{x}10^{-3}\ (k_f)^{0.5}$, where k_f is in darcys.

THE WIDEST FRACTURE DOMINATES FLOW



MATRIX OR FRACTURE FLOW?



ESTIMATING FRACTURE PERMEABILITY FROM TRACER TRANSIT TIMES

Assume the widest fracture dominates flow.

$$k_f = q\mu L/[h_f w_f \Delta p] = (L h_f w_f/t)\mu L/[h_f w_f \Delta p] = (L^2 \mu)/(\Delta p\, t)$$

Where:

L is fracture length (~distance between wells),

μ is fluid viscosity (usually of water),

Δp is the pressure drop between wells,

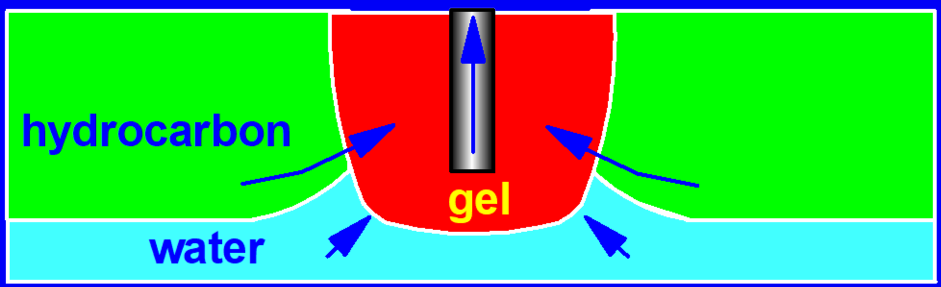
t is tracer transit time between wells.

CATEGORY D:

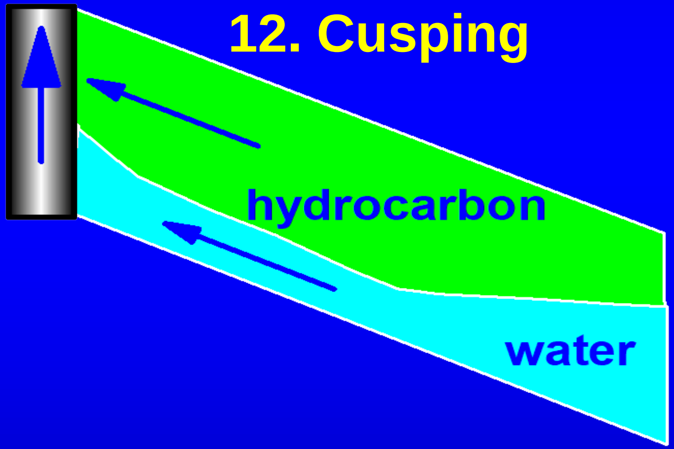
MOST DIFFICULT PROBLEMS

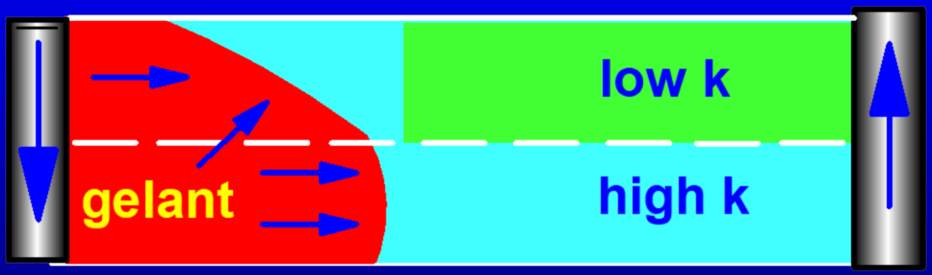
GELANT or GEL Treatments Should NOT Be Used

11. Three-Dimensional Coning



12. Cusping





13. Channeling through strata (no fractures), with crossflow.

FOURTH SET OF DIAGNOSTIC TESTS

Is the problem accentuated by crossflow?

- **Pressure test between zones,**
- **Various logs for determining fluid saturations, permeabilities, porosities, and lithologies**
- **Injection/production profiles**
- **Simulation**
- **Seismic and geophysical methods**

PREDICTING EXCESS WATER PRODUCTION
FACTORS LEADING TO PROBLEMS

1. Bad cement or factors inhibiting cementation.
2. Corrosive brines or gases.
3. Wellbore abuse during work-overs or well interventions.
4. Natural fractures (if oriented wrong).
5. Large permeability contrasts.
6. Low permeability rock (if induced fractures are oriented wrong).
7. Viscous oils or unfavorable mobility ratios.
8. Close proximity of an aquifer or gas cap.
9. Crossflow, under the wrong conditions (Items 5, 6, and 7 above).
10. Particulates or emulsions in injection water.

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Excess Water Production Problems and Treatment Categories
(Categories are listed in increasing order of treatment difficulty)

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