



## Physical mechanisms of deep bed filtration with application to the problems of petroleum industry

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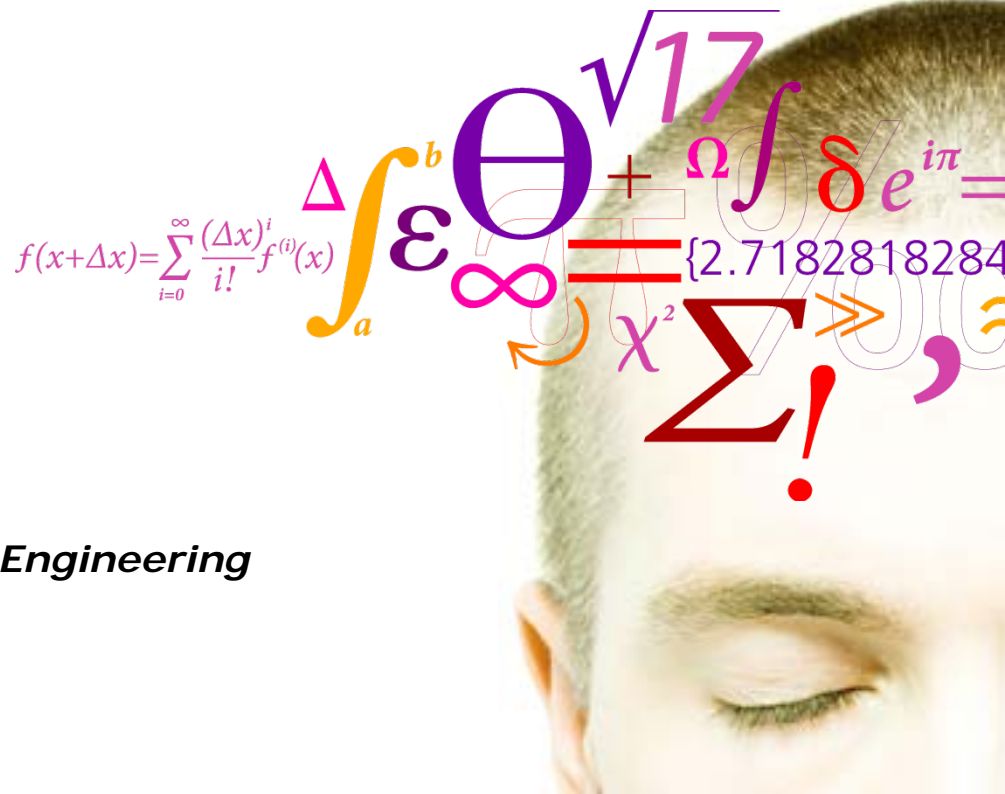
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# Physical mechanisms of deep bed filtration with application to the problems of petroleum industry

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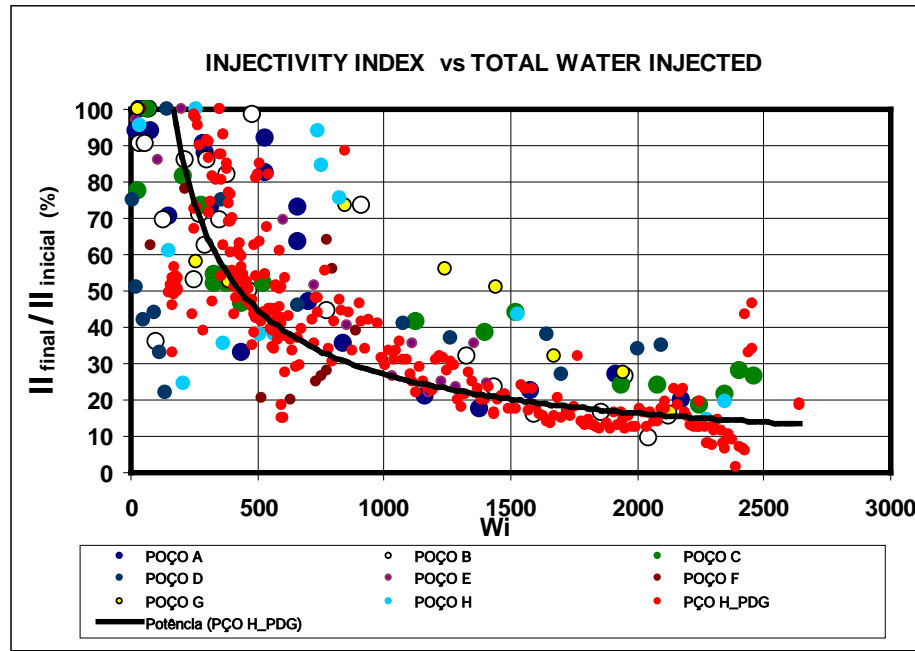
**Center for Energy Resources and Engineering  
Technical University of Denmark**



Why to study filtration in reservoir engineering?  
Is it a problem or an application in petroleum industry?

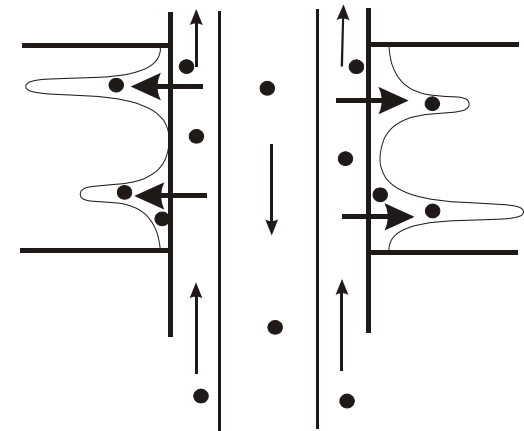
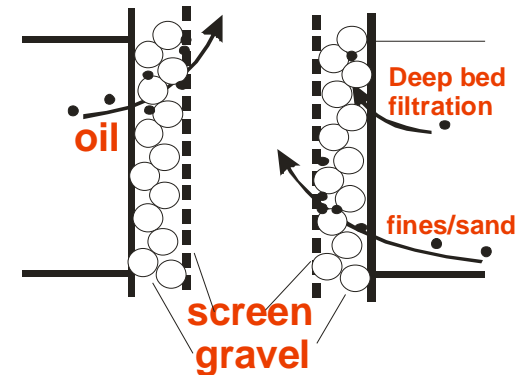
# **PROBLEMS AND APPLICATIONS OF FILTRATION IN PETROLEUM INDUSTRY**

# Problems



1. Injectivity decline during water injection
2. Drilling mud filtration creates filter cakes
3. Swelling and migration of reservoir fines (clay)

## Productivity decline for the gravel pack with screen



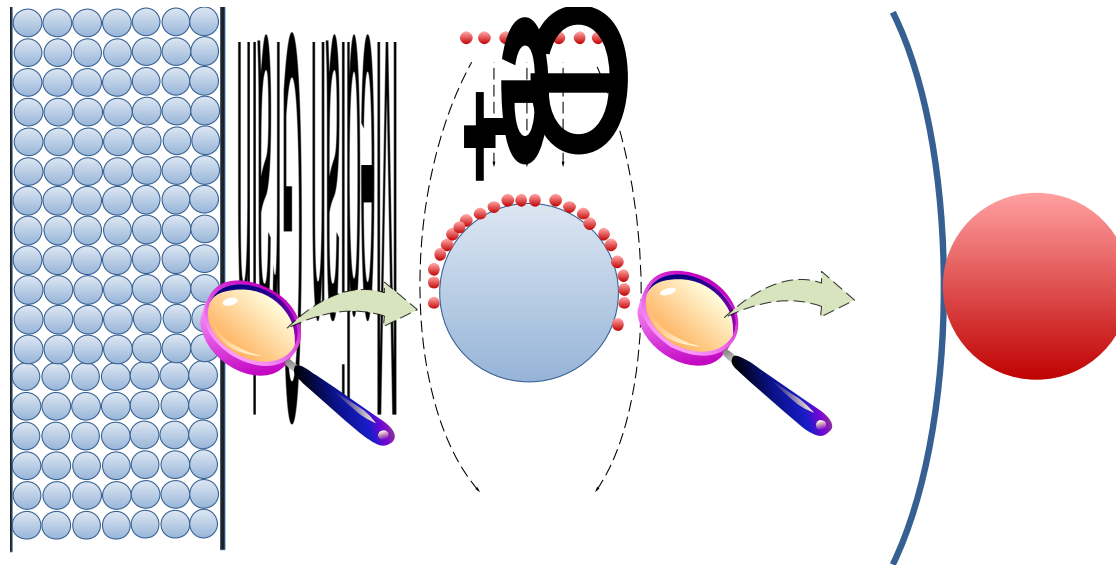
## Applications within EOR

- Erosion of the rock
  - Filtration in water swept zones
  - injection of carbon dioxide in chalk reservoirs
- Filtration of large molecules
  - e.g. polymer flooding, CDG flooding
- Propagation of bacteria in porous media
  - e.g. microbial enhanced oil recovery (MEOR)

**Problematic filtration: damage evaluation, control**  
**Applied filtration: flooding performance prediction**  
**Anyway, we need a good filtration model.**

# **CLASSICAL FILTRATION THEORY**

# Classical filtration theory (CFT):



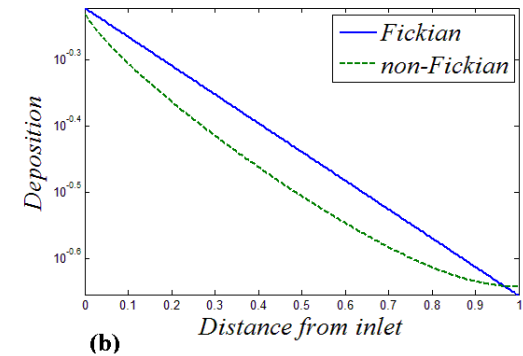
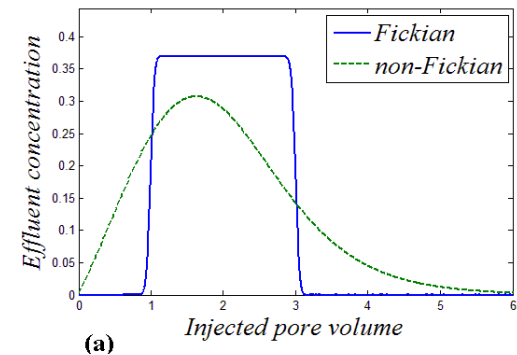
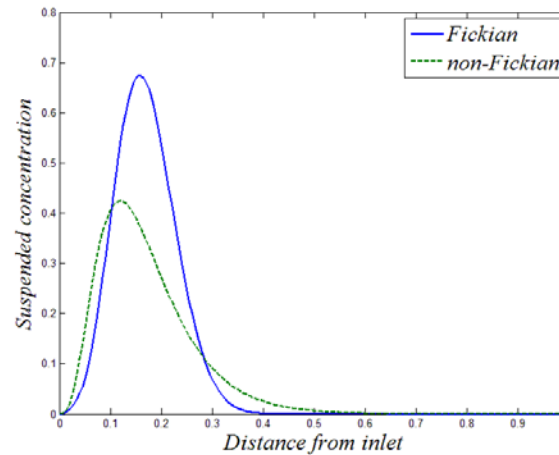
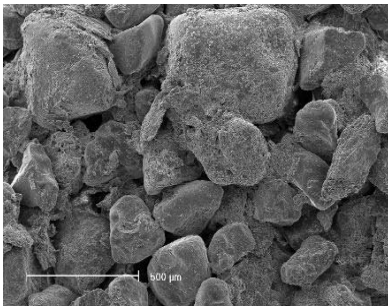
- Bed
- Uniform-sized and uniform-shaped
- Attachment
- Advection dispersion equation(ADE) <sup>[1]</sup>
- Einstein's Random walk theory<sup>[2]</sup>

Classical filtration theory(CFT) is widely applied in the chemical industry. Is the CFT also sufficient for the filtration in nature? Such as reservoirs? If not, do we have the techniques for modeling such processes?

# **FILTRATION MECHANISMS AND RECENT ADVANCES IN FILTRATION THEORY**

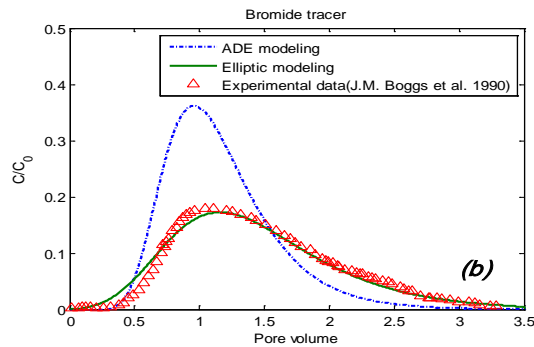
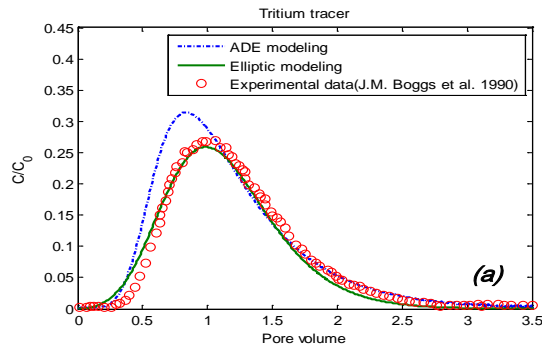


# 1. Non-Fickian transport

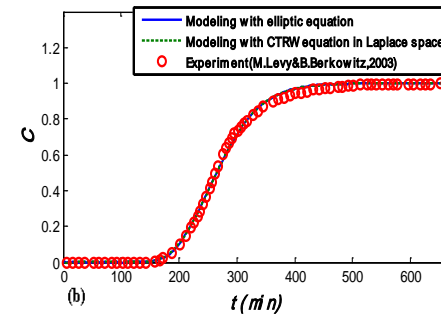
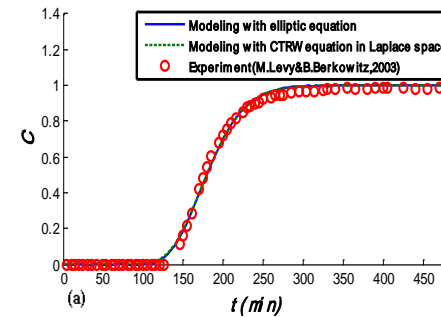


- SEM
- Non-uniform sizes & shapes
- Heterogeneity
- Non-Fickian transport [2-6]
- Continuous time random walk
- Elliptic equation [4-9]

# Comparisons with experiments<sup>[6,7]</sup>



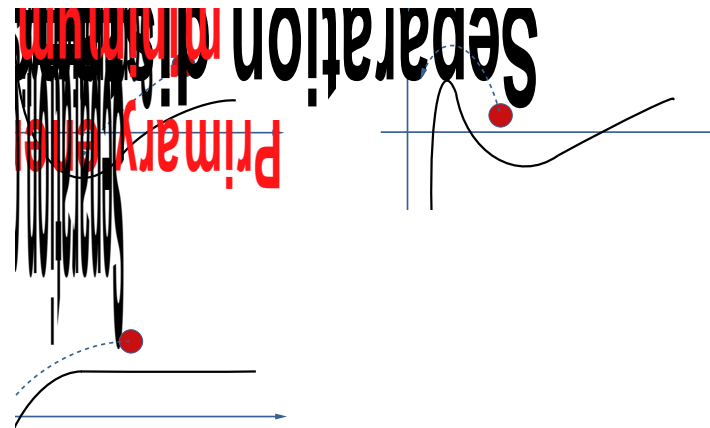
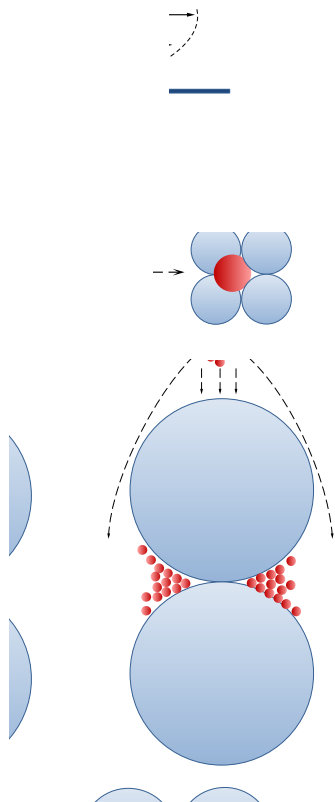
Porous media from underground formation, US military base



Uniform heterogeneity, (sand boxes in a sand matrix)

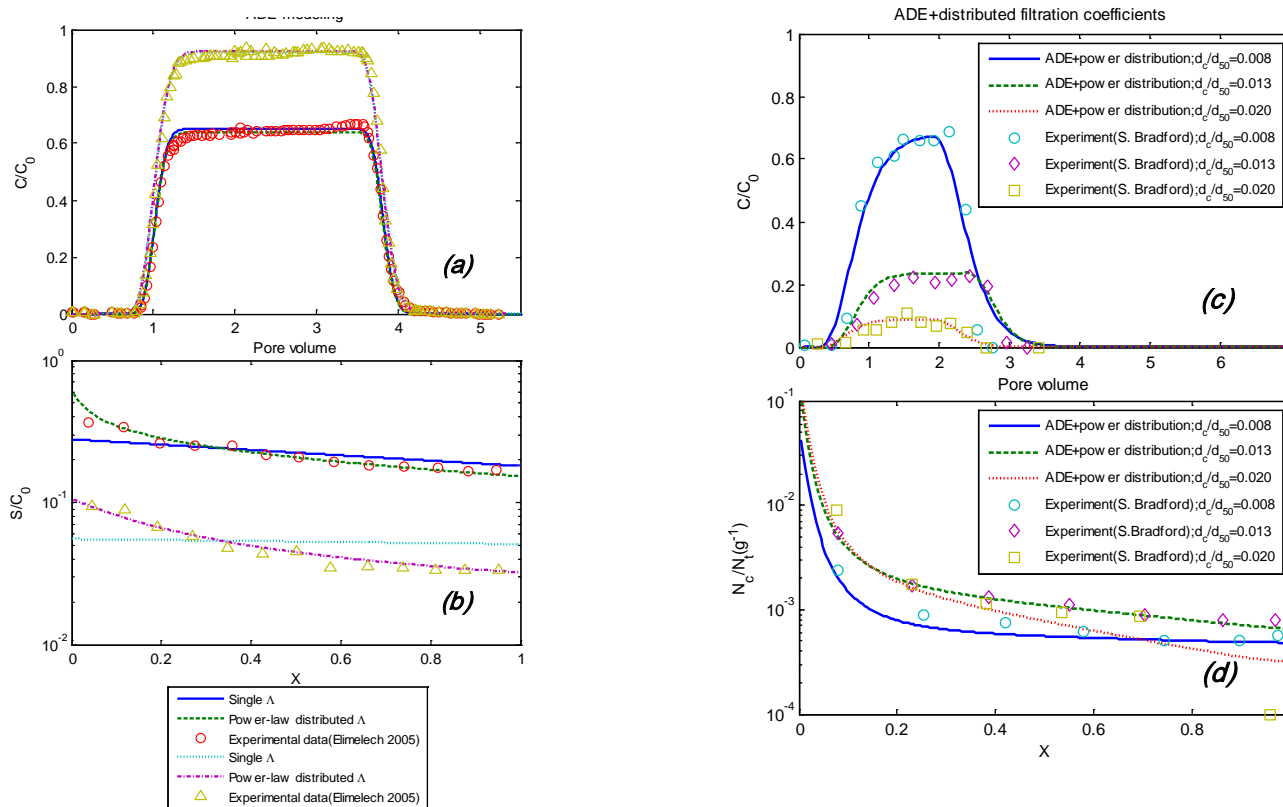
## 2. Polydisperse suspension<sup>[10-13]</sup>

### Heterogeneous particle-medium interactions



- Different sizes
- Accumulate at constrictions
- Size exclusion
- Different surface charges

# Comparisons with experiments

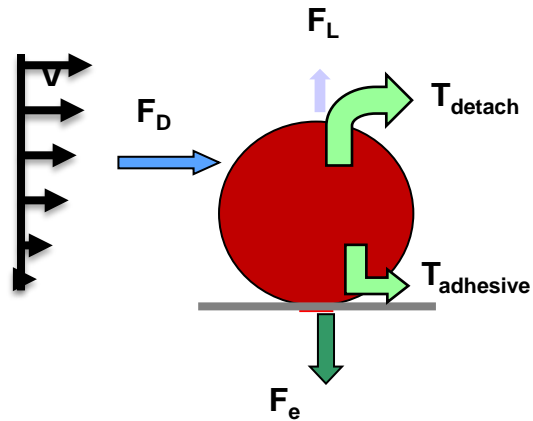


Experiments: Polydisperse colloids

[6,7,11,12]

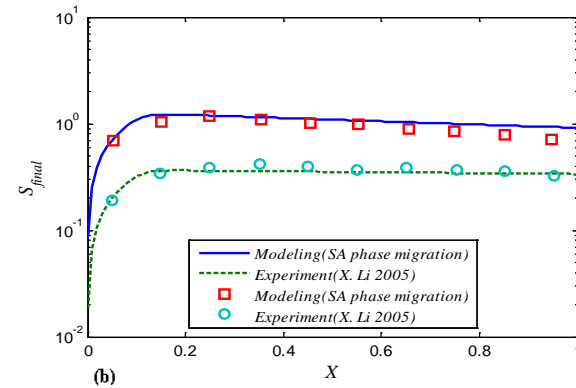
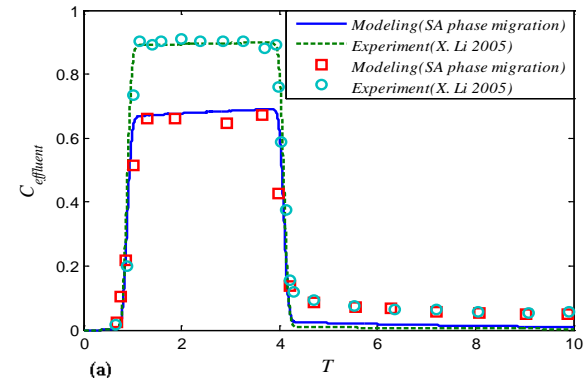
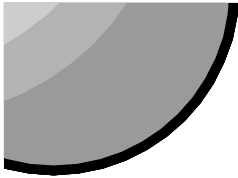
Model: Distributed filtration coefficients

### 3. Erosion of porous media



1. Torque balance analysis
2. Various forces exerting on captured particles
3. Balance determines whether particles to stay or release

# Comparisons with experiments

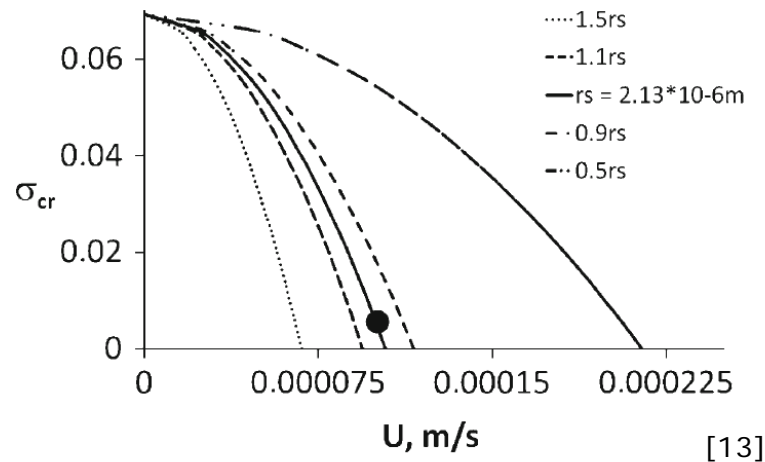


[10]

# 4. Maximum retention function

Torque balance analysis →  
 Express maximum retention  
 as a function of [13]:

1. Water salinity
2. Water velocity
3. Particle size
4. ...

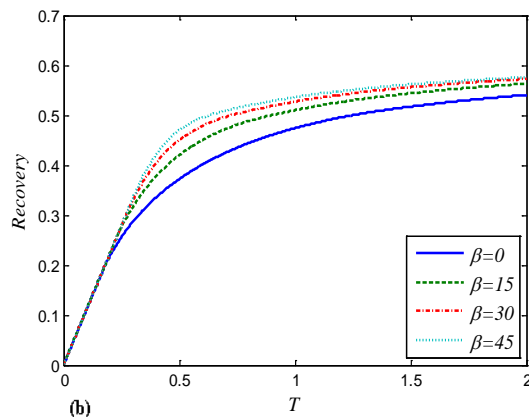
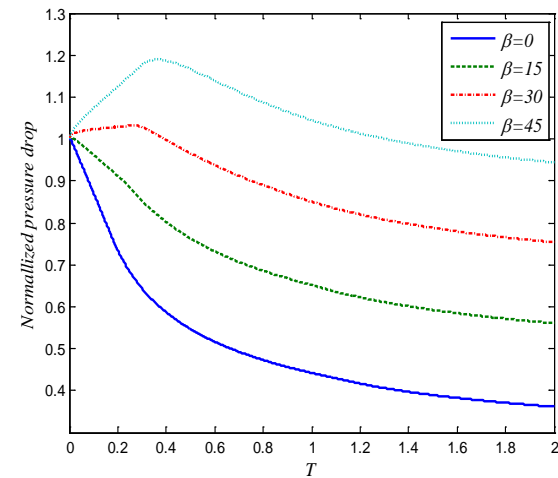
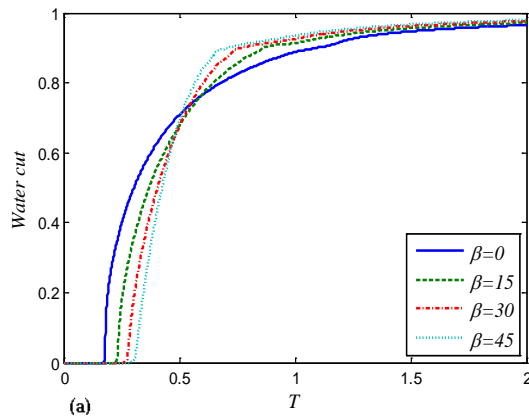


[13]

# Possible Application: Migration of fines in waterflooding for EOR



# Water-cut and recovery



Here  $\beta$  is the formation damage coefficient.

## Conclusions

- The problems and application of filtration in petroleum industry calls for more advanced models than the classical filtration theory.
- More advanced filtration models are available for filtration in reservoirs, to account for:
  - Median heterogeneity
  - Polydisperse suspension
  - Erosion of reservoir formation
  - Migration of reservoir fines

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