Reservoir Characterization from Generalized Well Test Data

With the Aid of System Identification Techniques

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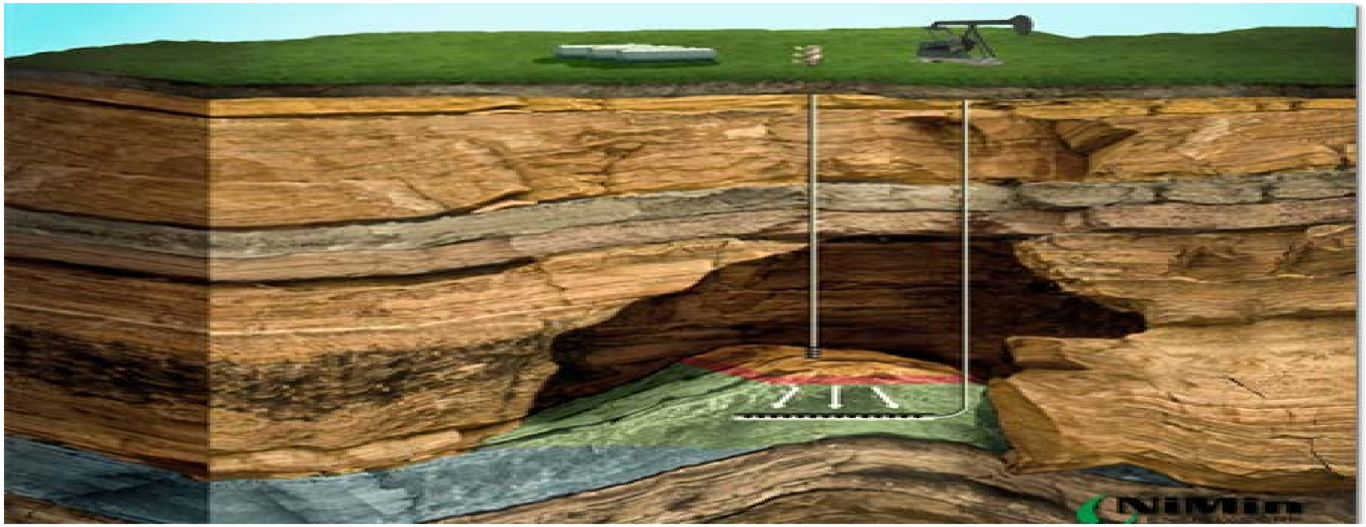
Oil and Gas Reservoir

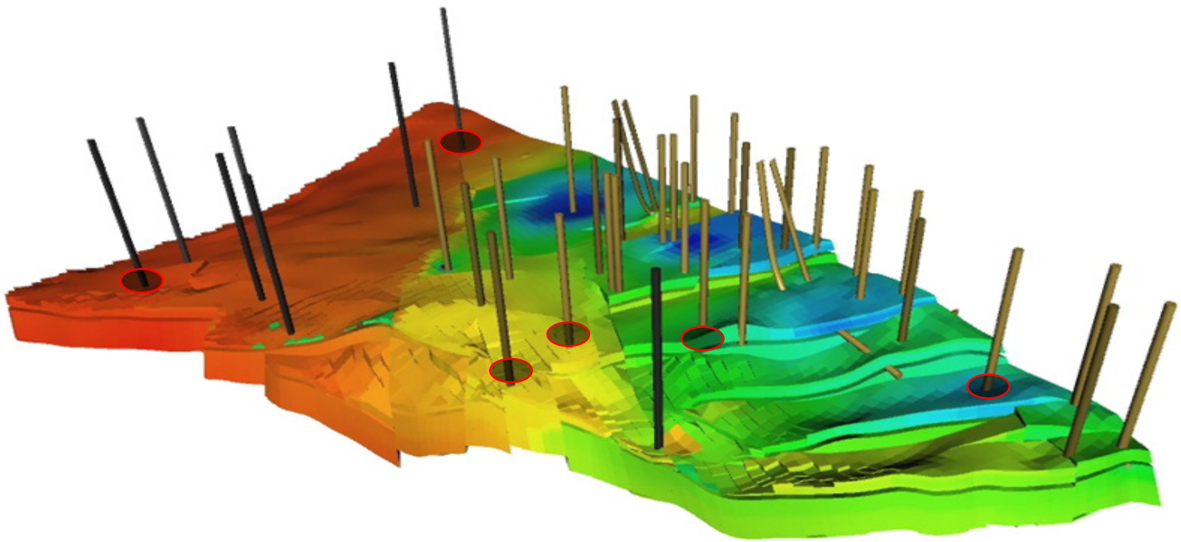


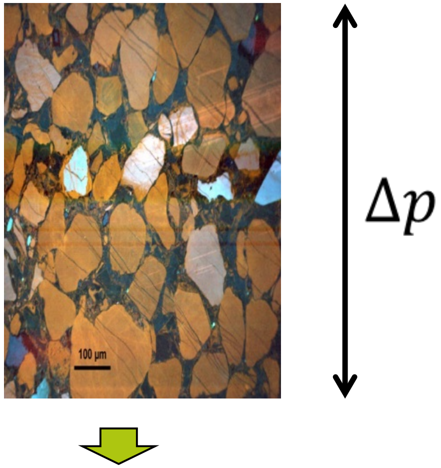
- Reservoir ~ porous rock
- Depth ~ 1000-4000 m
- Long term production life ~ 20 – 100 year

- A **model** is essential to manage reservoir development and oil production

The Reservoir Model

- **Permeability** distribution determines flow pattern.
- Estimate the average permeability around the wells by **well test**.

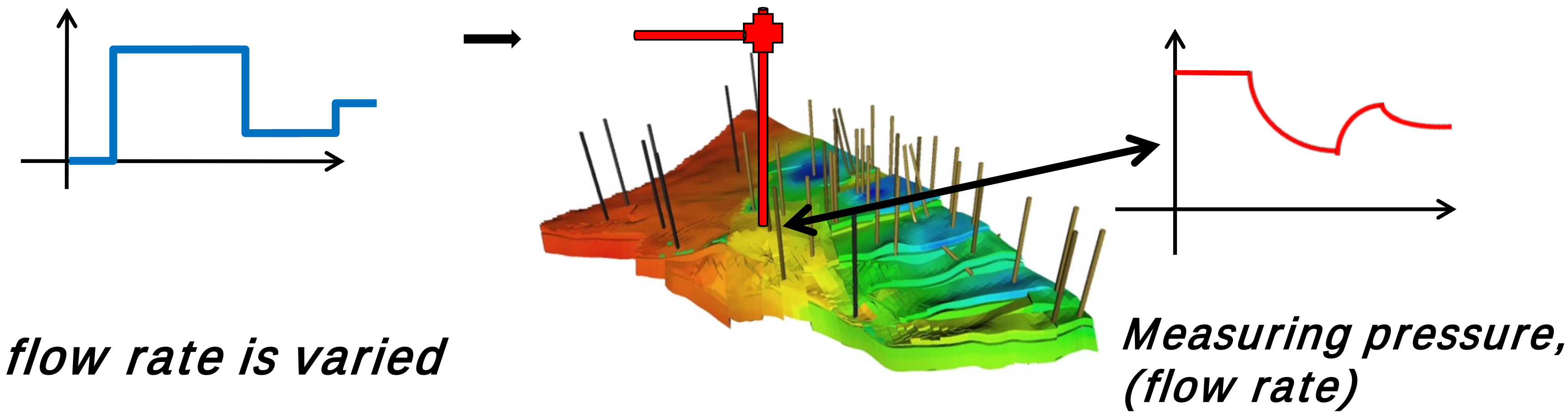




$q(t)$

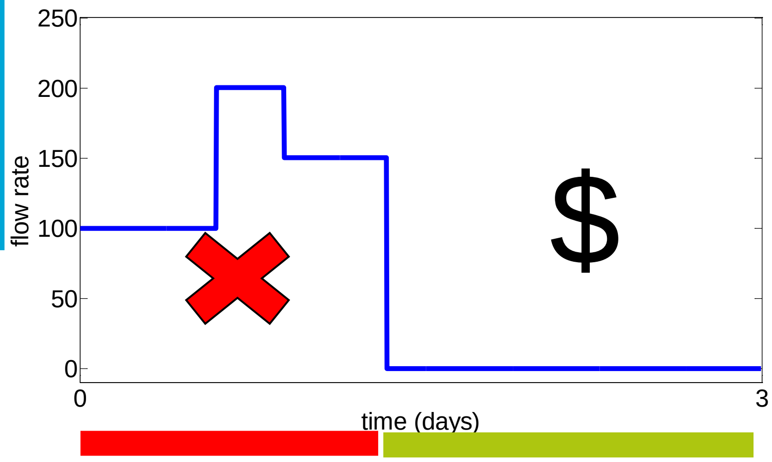
$$q(t) \propto \boldsymbol{k}\frac{dp}{dx}$$

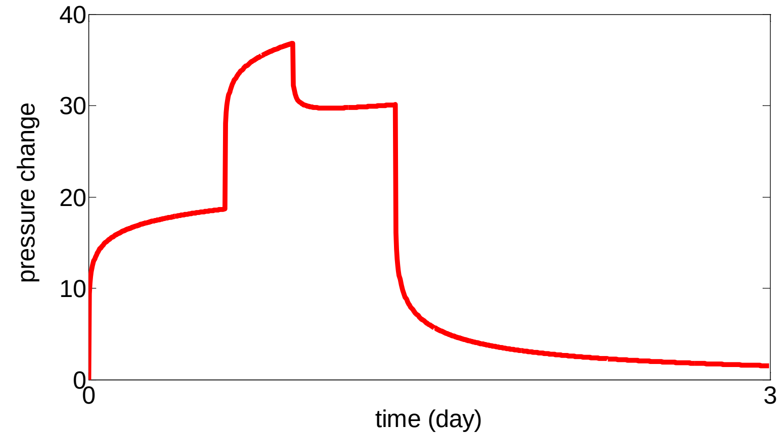
Conventional Well Test



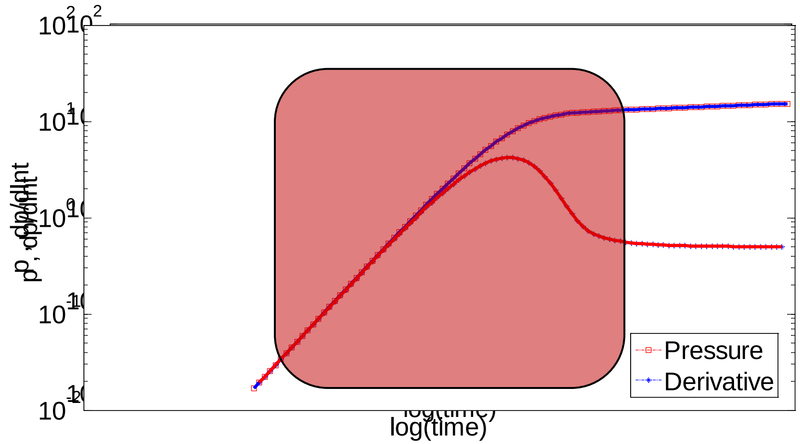
- Manipulating the flow rate at surface.
- Response contains flow period responses.
- Pressure and flow variations are related by pressure transient analysis

Steps in Conventional Well Test Analysis





- ❑ Log-Log plot for pressure and its derivative for (biggest)BU flow period
- ❑ Model selection (type curve matching)
- ❑ Parameter estimation

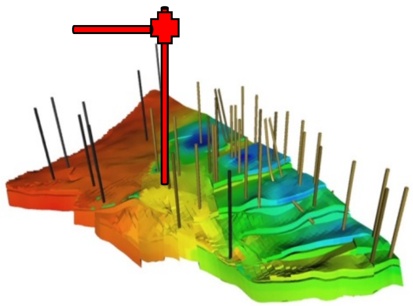


× *Only one shut-in period is used.*

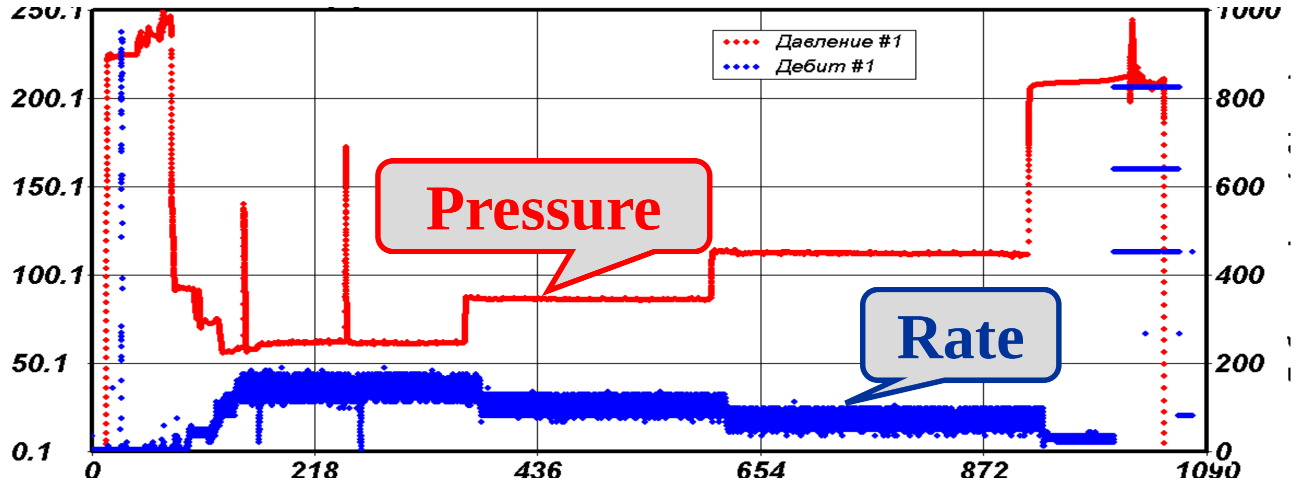
× *Loss of production.*

× *Effect of wellbore storage model in the data masks the reservoir response.*

Data From a PDG



Permanent down-hole gauge



- ❑ PDG data is recorded under uncontrolled circumstances.
- ❑ Downhole pressure data for months (even years)
- ❑ Information of the reservoir (no wellbore dynamic)

Research Question

The research problem in well test:

Given a set of measured (noisy) p^m_{bh} , and variable (noisy)q^m_{bh}

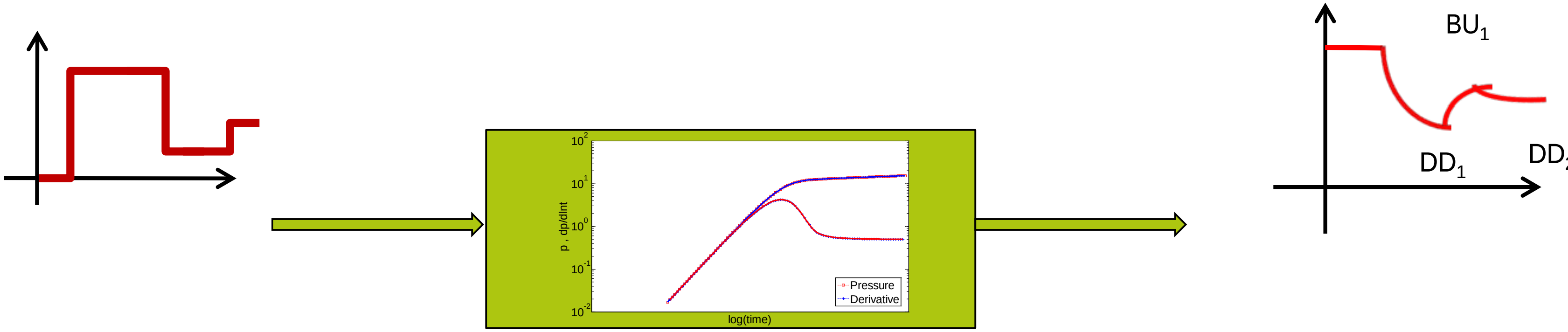
1) Identify the reservoir system
2) Estimate the physical parameter.

The classical system identification problem:

given (noisy) u, (noisy) y of plant G_0 and possibly external signal r,

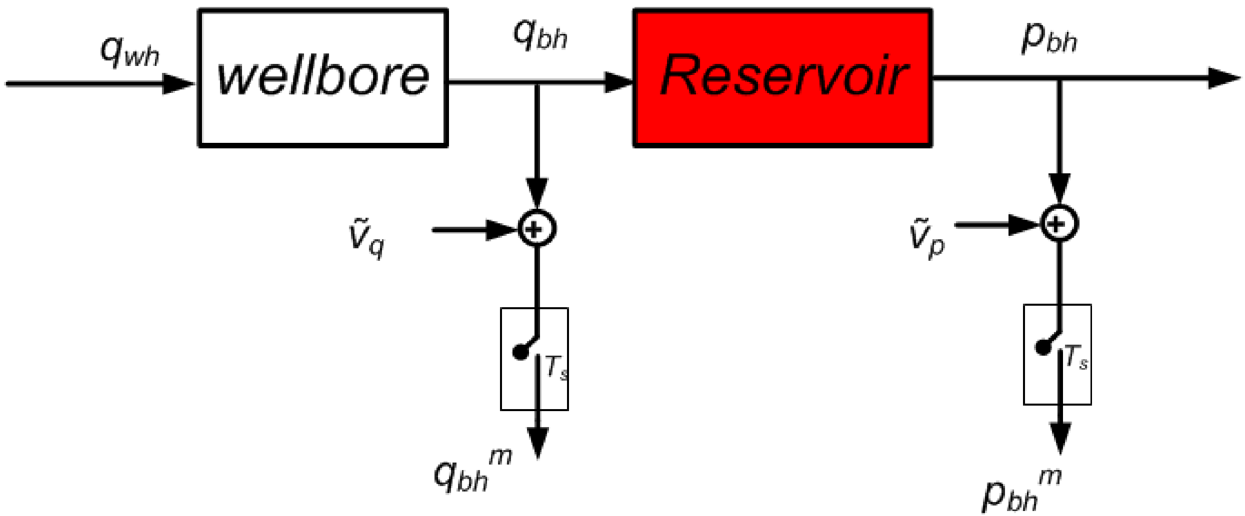
1) Identify a plant model G
(for control, simulation or prediction)

Definition of the Problem



flow rate is varied

pressure is changed

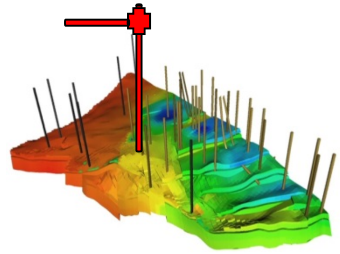


Outline

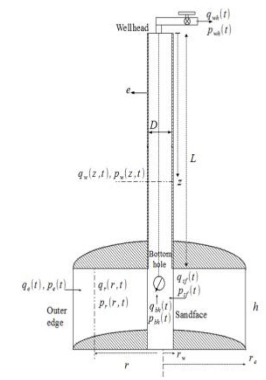
permeability
wellbore damage

physical
parameter
estimation

reservoir



single well

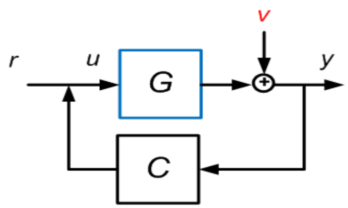


causal
structure

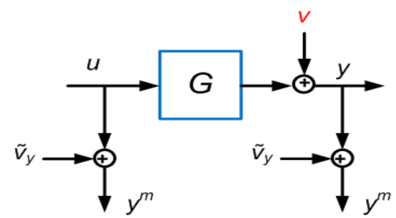
system
identification

$$G\,(q^{-1}) = \frac{B(q^{-1})q^{-(f+1)}}{F(q^{-1})}$$

closed -loop



errors-in-variable



Fluid Flow in the Wellbore

Mass conservation

Momentum conservation

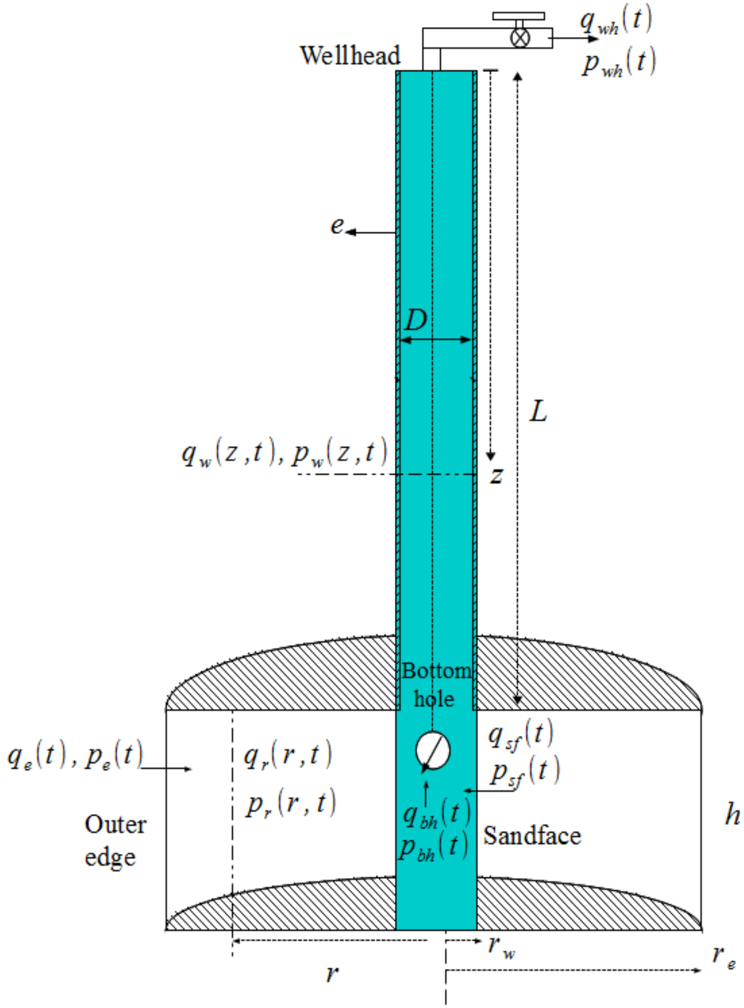
B.C.:

Wellhead side: flow rate

Bottomhole side: pressure

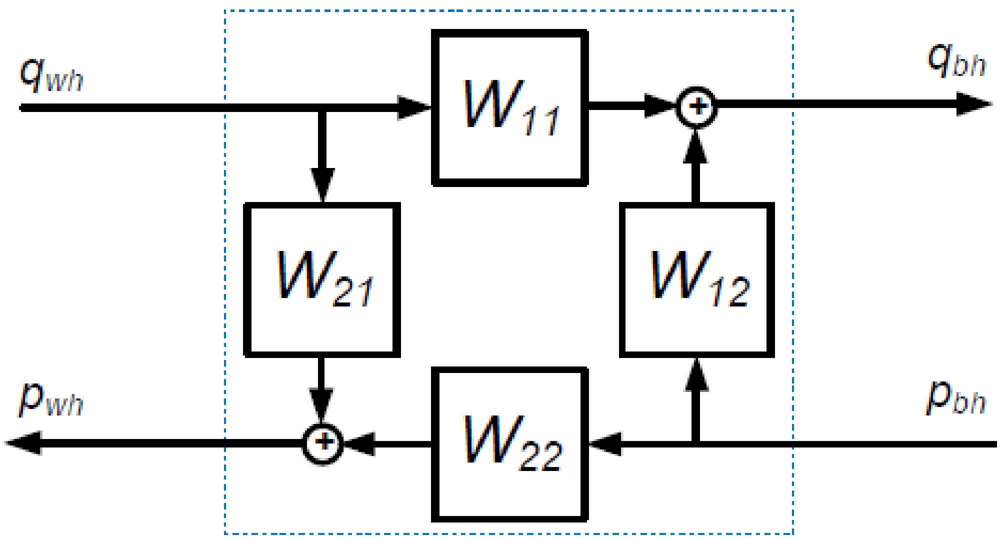
Slightly compressible single phase fluid model

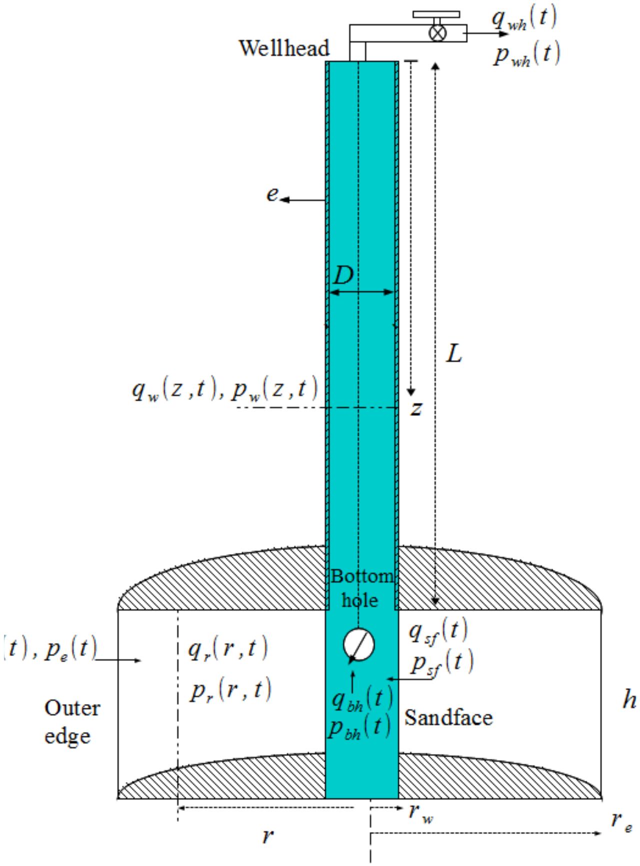
$$\begin{bmatrix} \mathcal{Q}_{bh}(s) \\ \mathcal{P}_{wh}(s) \end{bmatrix} = \mathbb{W} \begin{bmatrix} \mathcal{Q}_{wh}(s) \\ \mathcal{P}_{bh}(s) \end{bmatrix}$$



$$\mathcal{Q}_{bh}(s) = W_{11}(\beta, s)\mathcal{Q}_{wh} + W_{12}(\beta, s)\mathcal{P}_{bh}(s)$$

$$\mathcal{P}_{wh}(s) = W_{21}(\beta, s)\mathcal{Q}_{wh} + W_{w2}(\beta, s)\mathcal{P}_{bh}(s)$$





Fluid Flow in the Reservoir

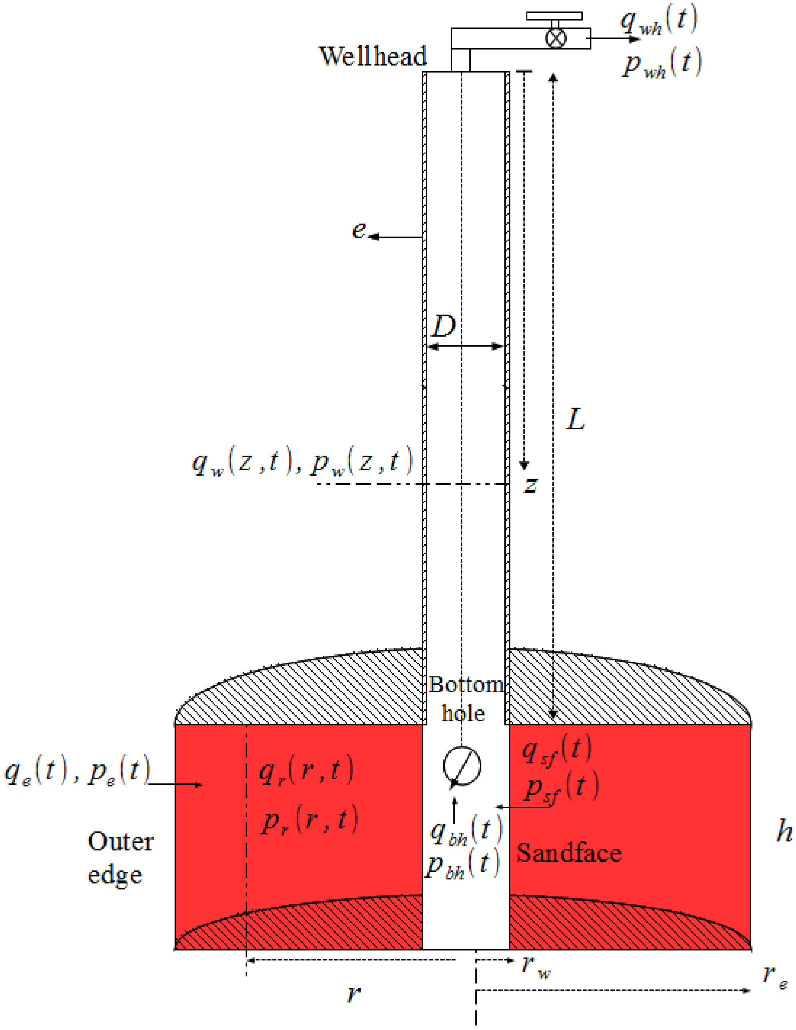
Diffusivity equation

Darcy's Law

B.C.:

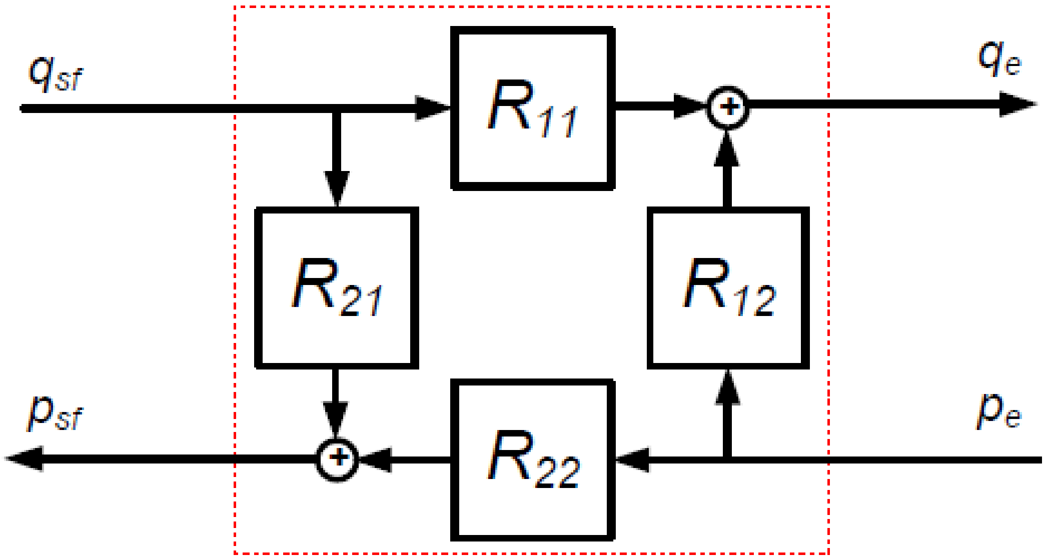
- Sandface side: flow rate
- Outer edge side: pressure

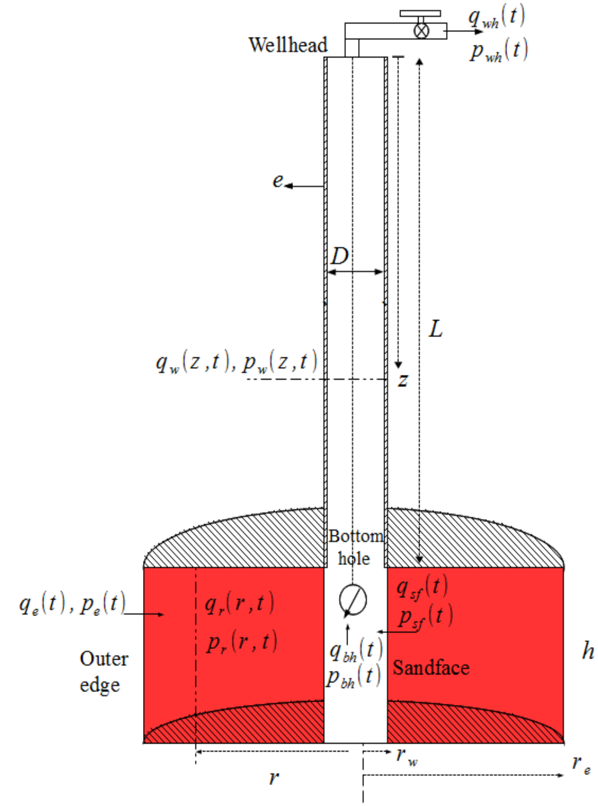
$$\begin{bmatrix} \mathcal{Q}_e(s) \\ \mathcal{P}_{sf}(s) \end{bmatrix} = \mathbb{R} \begin{bmatrix} \mathcal{Q}_{sf}(s) \\ \mathcal{P}_e(s) \end{bmatrix}$$



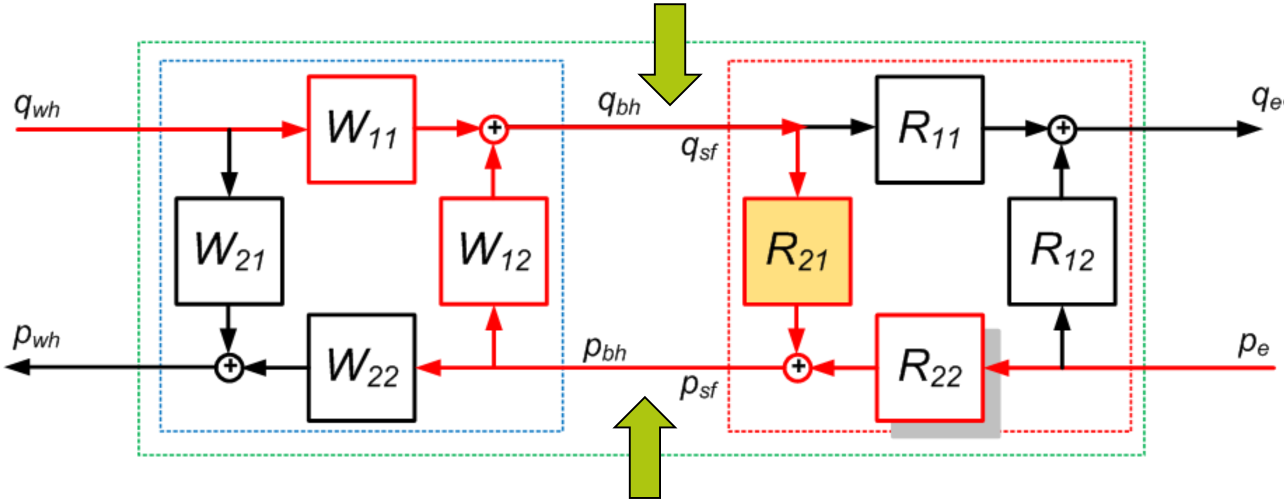
$$\mathcal{P}_{sf}(s) = R_{21}(\beta, s)\mathcal{Q}_{sf} + R_{22}(\beta, s)\mathcal{P}_e(s)$$

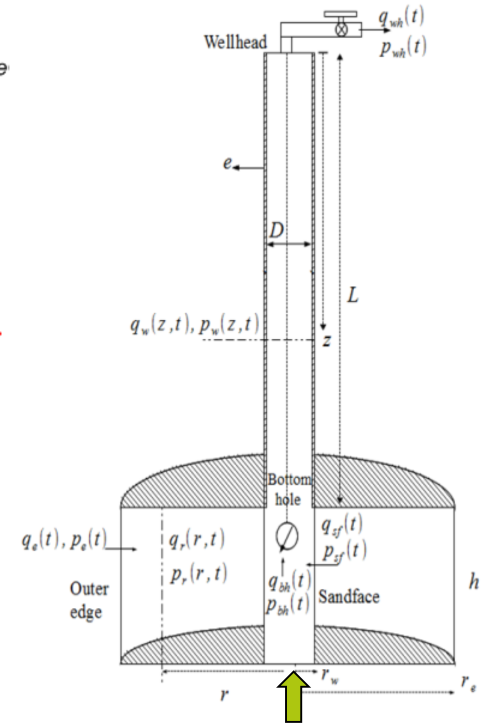
$$\mathcal{Q}_e(s) = R_{11}(\beta, s)\mathcal{Q}_{sf} + R_{12}(\beta, s)\mathcal{P}_e(s)$$

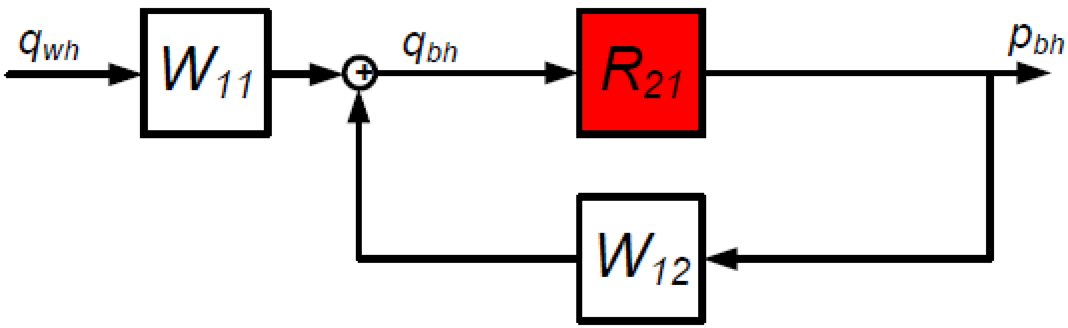




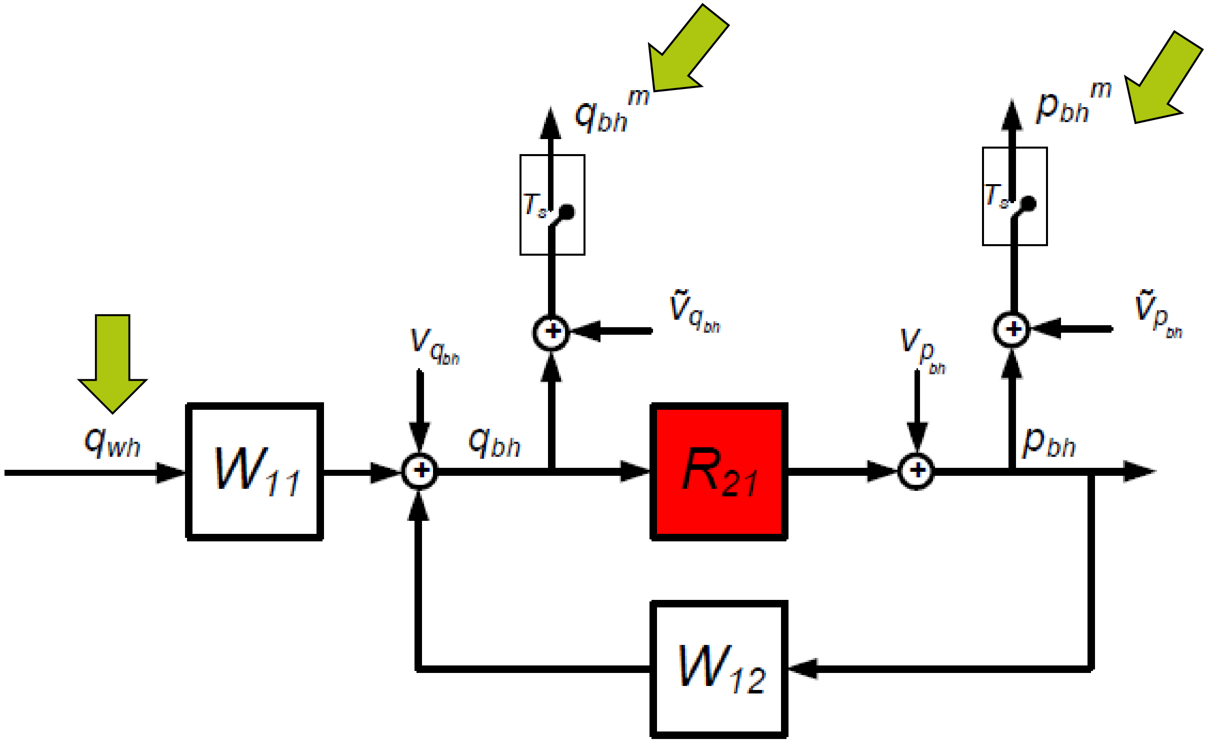
Bilaterally Coupling the Systems

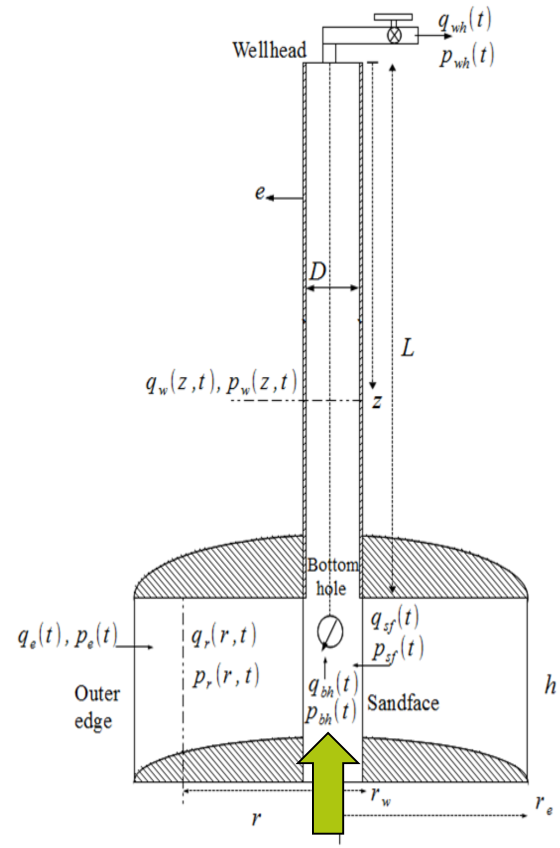






Well test measurements





- ❑ A Errors-In-Variable (EIV) in Closed Loop problem
- ❑ Not possible to identify R21 with $q^m bh$, $p^m bh$

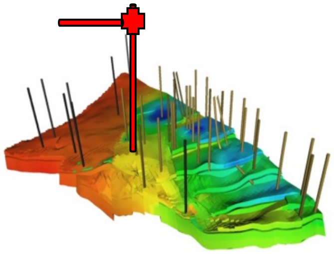
Söderström, et al. (2012). Can errors-in-variables systems be identified from closed-loop experiments? Automatica.

Outline

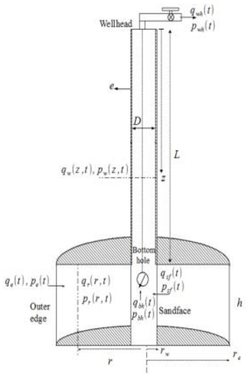
permeability
well damage
porosity

physical
parameter
estimation

reservoir
model



single well



causal
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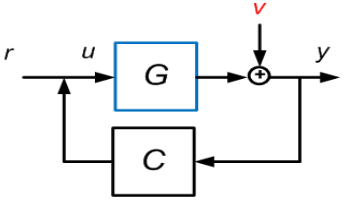
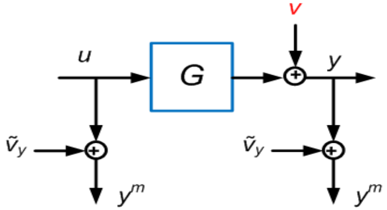
$$G\,(q^{-1}) = \frac{B(q^{-1})q^{-(f+1)}}{F(q^{-1})}$$

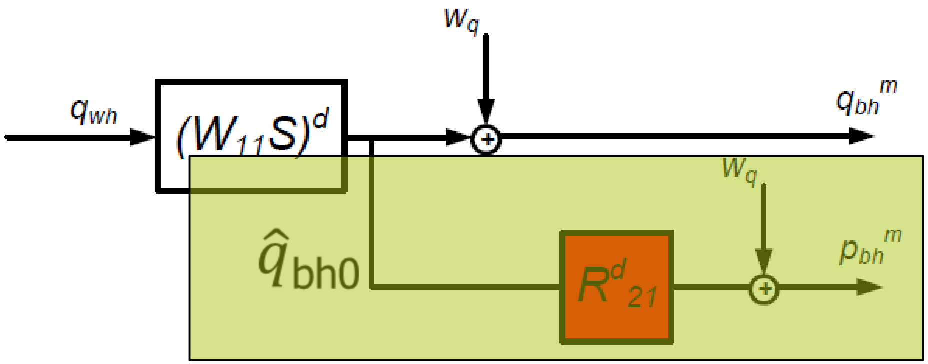
closed -loop

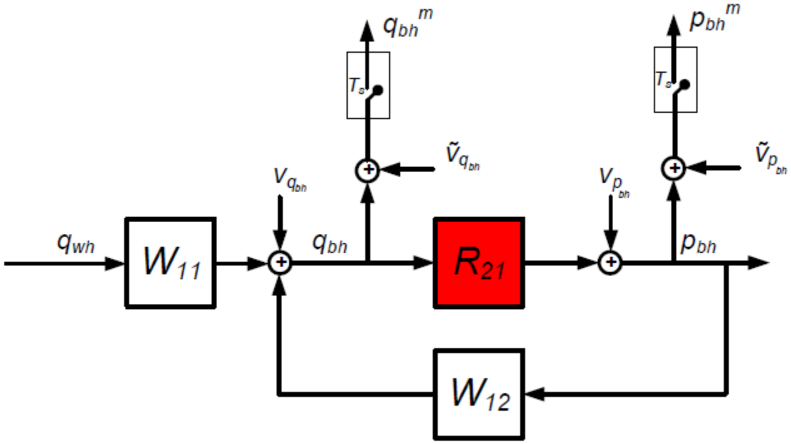


errors-in-variable



Two-stage closed-loop identification





First open loop identification

$$q_{bh}^m(k) = G_{fs}(q^{-1}, \theta_0) q_{wh}(k) + w_q(k) \quad k = 0, \cdots N$$

$$\hat{q}_{bh_0}(k) = G_{fs}(q^{-1}, \hat{\theta}) q_{wh}(k) \quad k = 1, \cdots N.$$

Second open-loop identification

$$p_{bh}^m(k) = R_{21}^d(q^{-1}) \hat{q}_{bh_0}(k) + w_p(k)$$

The Research Problem

permeability
well damage
porosity

physical
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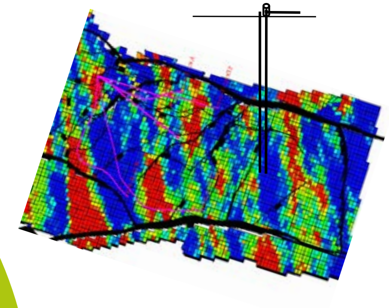
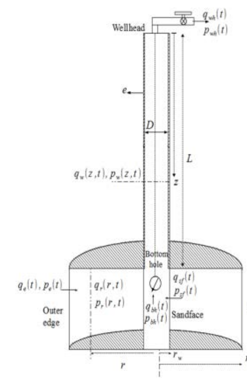
estimation

reservoir
model



single well



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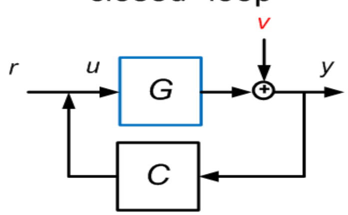
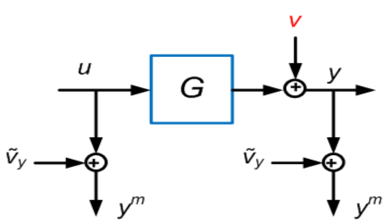
closed -loop



errors-in-variable



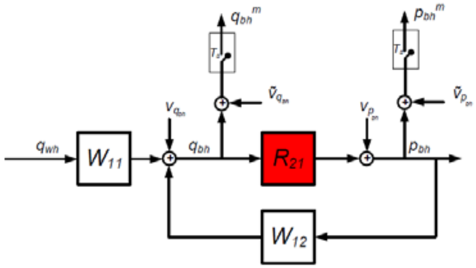
Physical Parameters Estimation

	Physic-based model	**Data-based model**
Time-domain	PDE equations	discrete-time data
Complex-domain	$R_{21}(s) = R_{11}(s,k,S)$	$\hat{G}_{ss}(z,\hat{\theta}_N) = \frac{B(z,\hat{\theta}_N)}{F(z,\hat{\theta}_N)}$
Frequency-domain	$R_{21}(k,S,j\omega)$	$\hat{G}_{ss}(e^{j\omega},\hat{\theta}_N)$

$$\hat{\beta} = \frac{1}{L}\arg\min_{\beta}\sum_{l=1}^{L}\left\| R_{21}(\beta, j\omega_l) - \hat{G}_{ss}(e^{j\omega},\hat{\theta}_N)\right\| W(\omega_l)$$

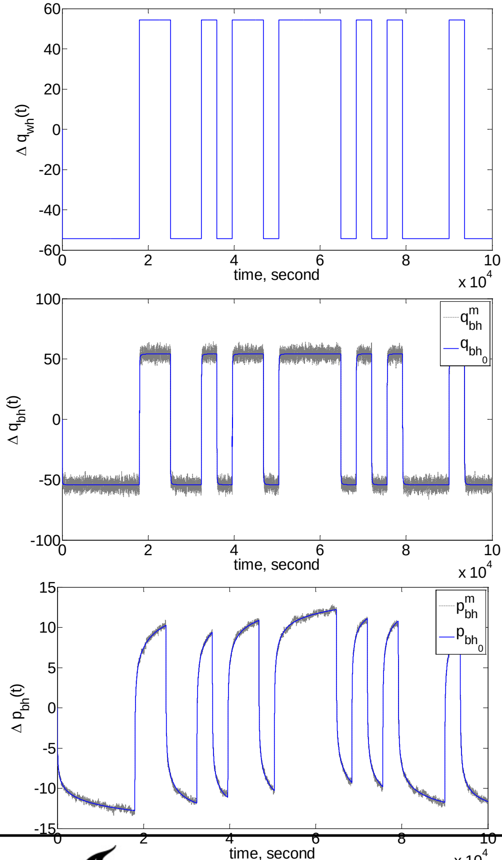
$$R_{21} = \frac{\mu}{2\pi k h r_w\sqrt{\frac{s}{\eta}}}\frac{I_{0e}K_{0w} - I_{0w}K_{0e}}{I_{0e}K_{1w} + I_{1w}K_{0e}} + S \qquad \hat{G}_{ss}(z,\hat{\theta}_N) = \frac{B(z,\hat{\theta}_N)}{F(z,\hat{\theta}_N)}$$

Case Studies



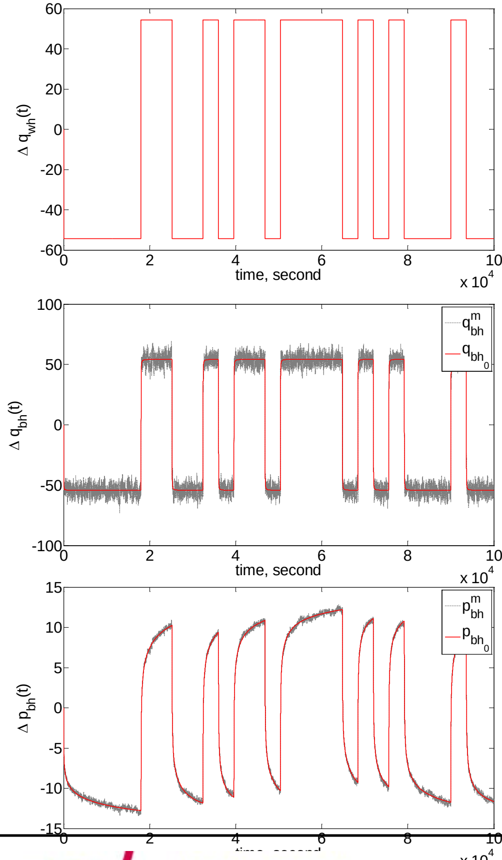
Case 1

Well:single-phase model



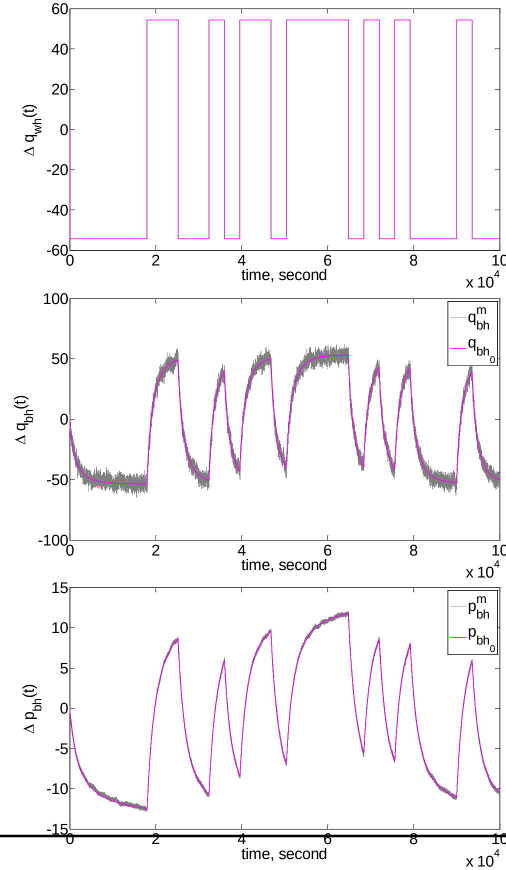
Case 2

Well:small WBS coef.



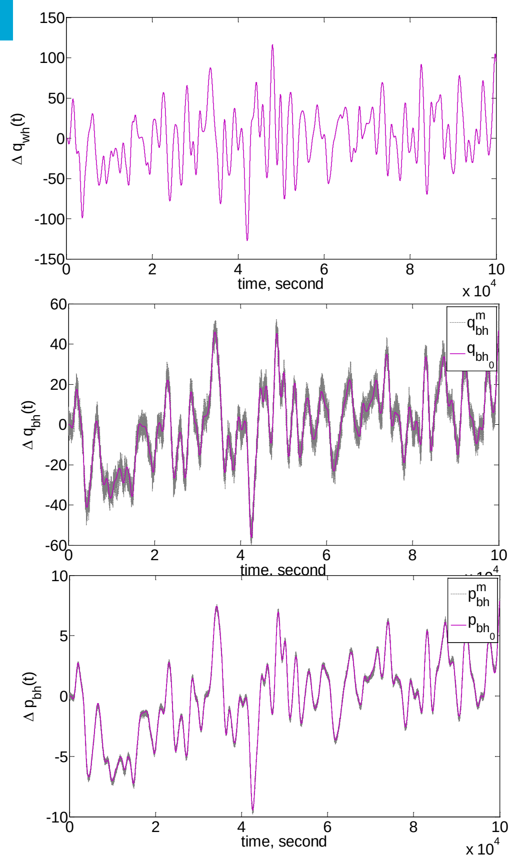
Case 3

Well:big WBS model

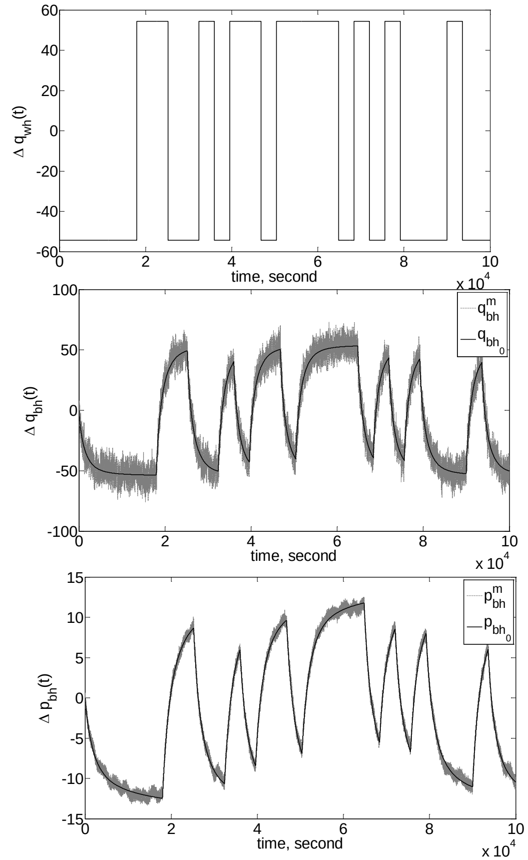


Case Studies

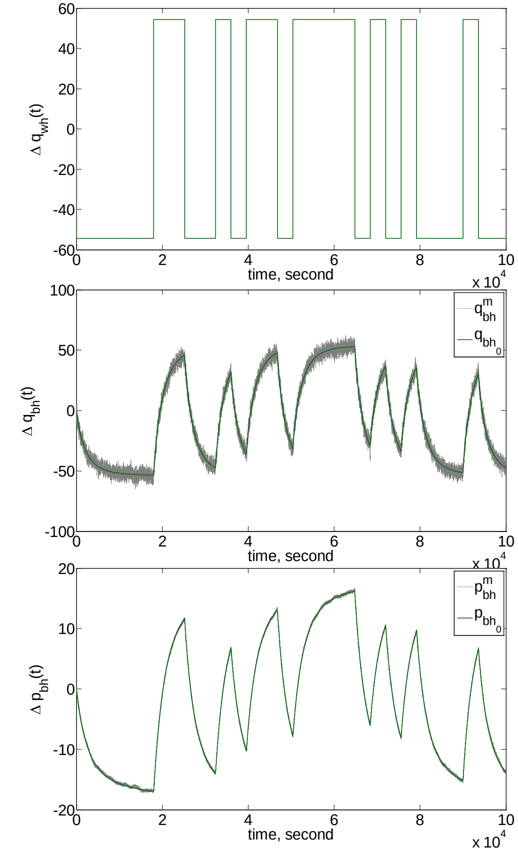
Case 4
Random input signal



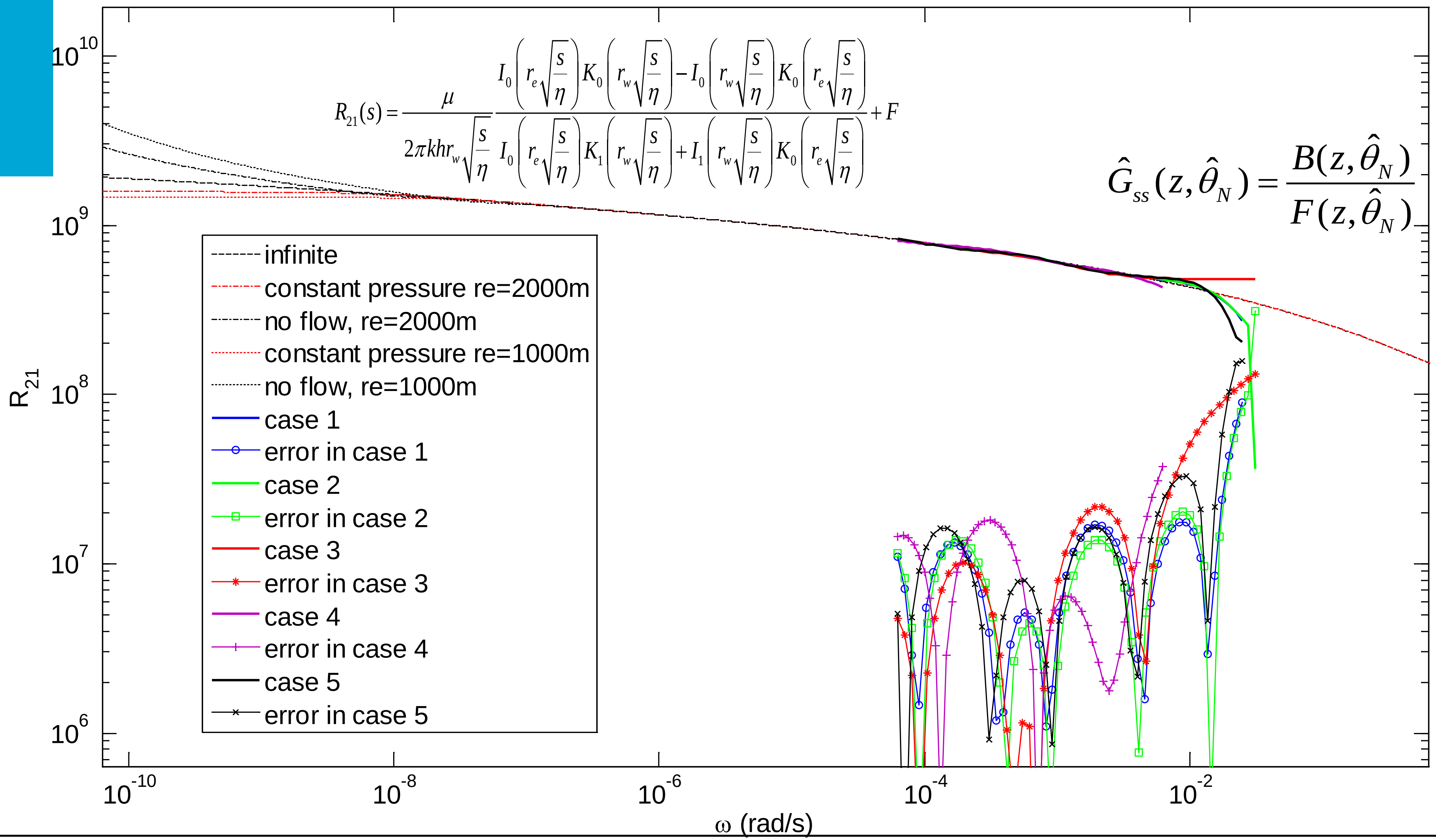
Case 5
Twice noise level



Case 6
Positive skin factor



Identified Reservoir Models



Estimated reservoir parameters

Cases 1-5:

K_{true} =200 mD
$Skin_{true}$ =0

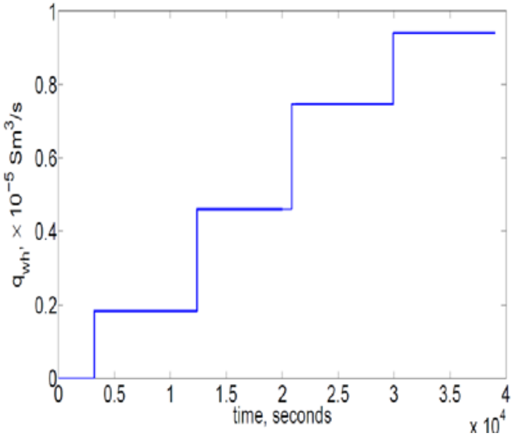
Cases 6:

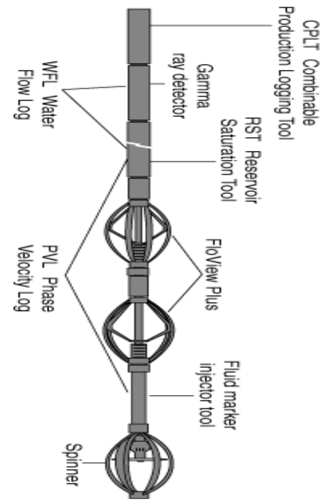
K_{true} =200 mD
$Skin_{true}$ =2

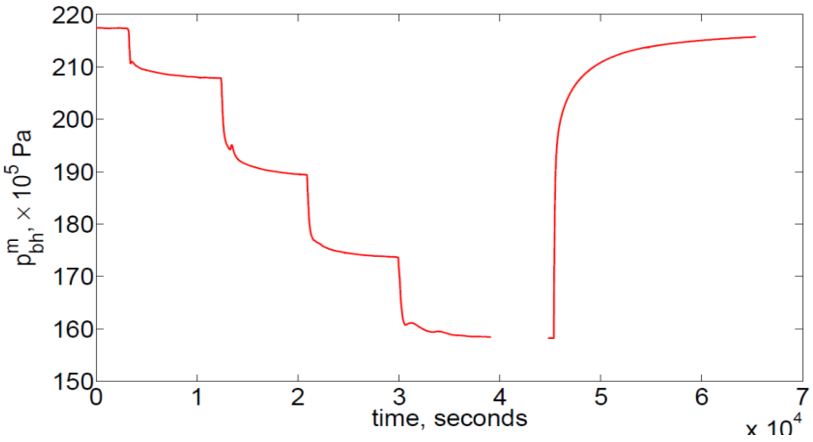
Table 5: Estimation Results

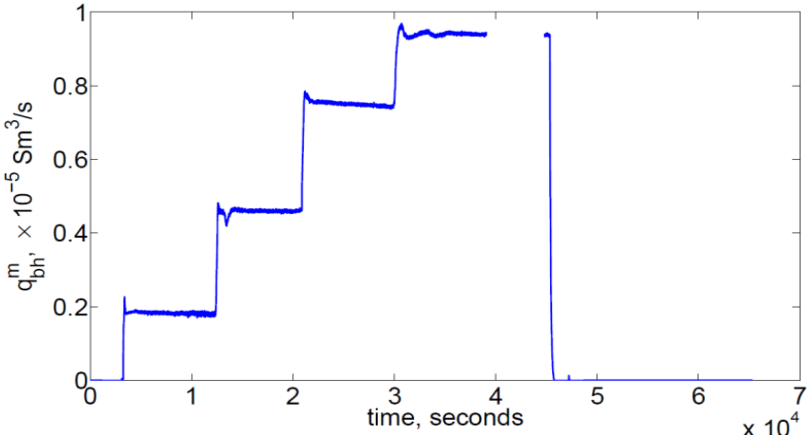
	Permeability (mD)	Skin
case 1	199.9	-0.03
case 2	204.3	0.05
case 3	199.5	-0.03
case 4	201.8	0.048
case 5	200.1	0.003
case 6	203.6	2.1

Field data – An onshore gas well

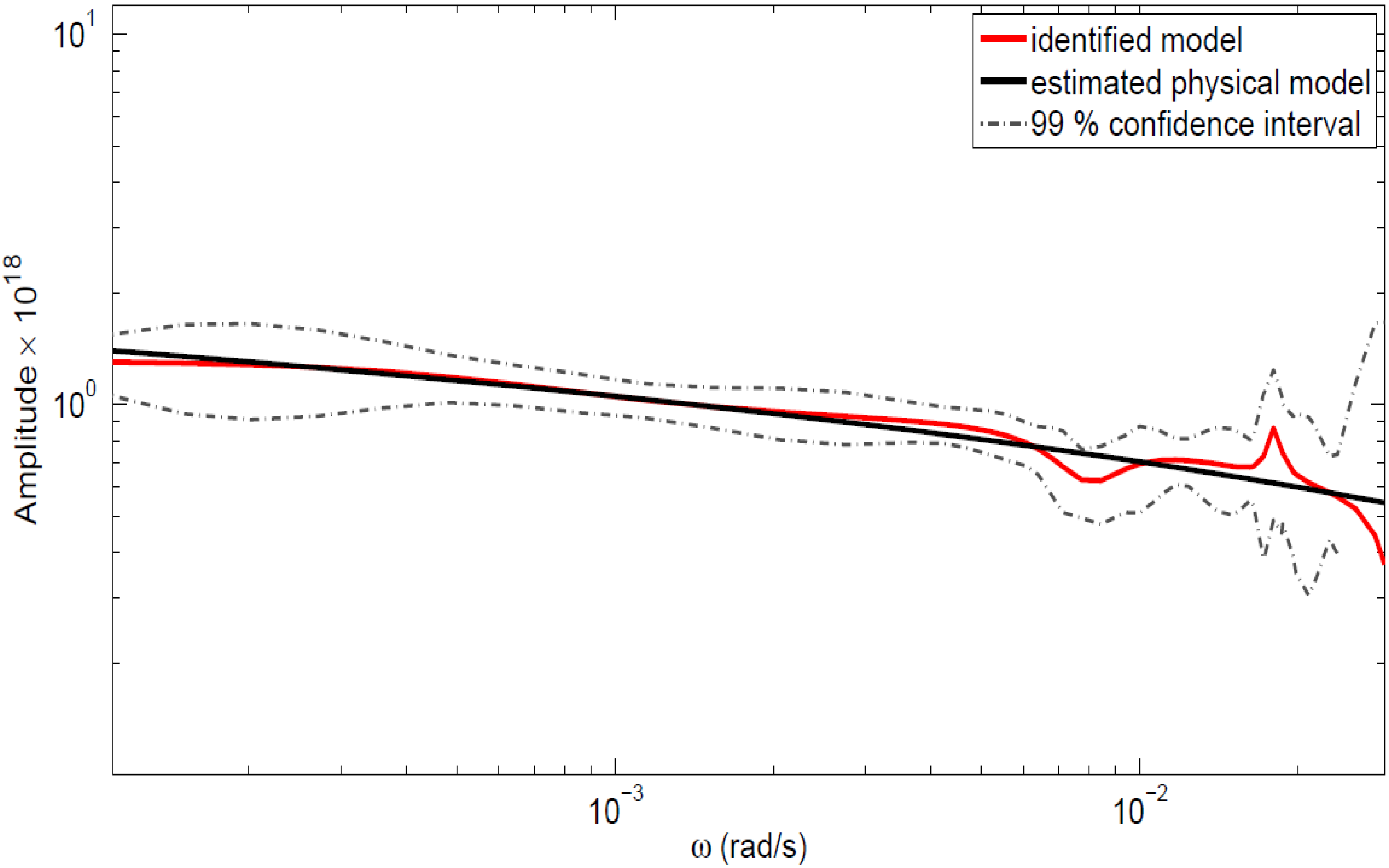








Field data – TS SI method result



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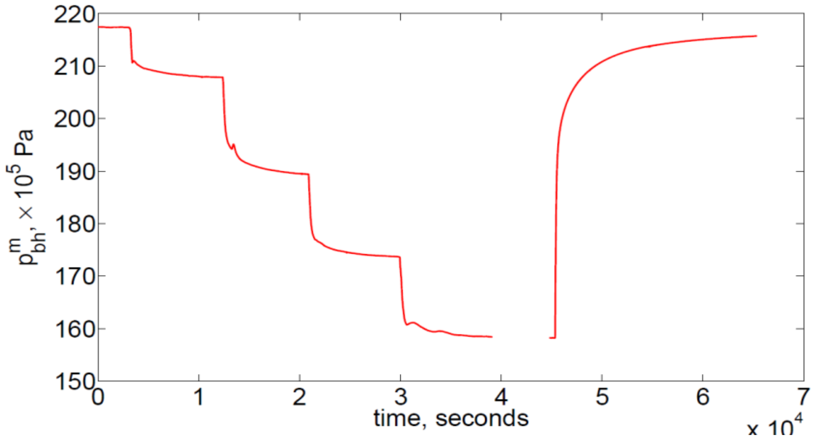
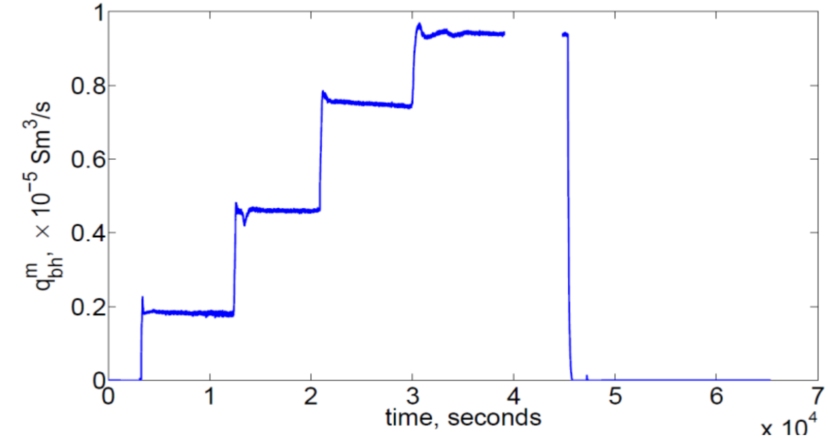
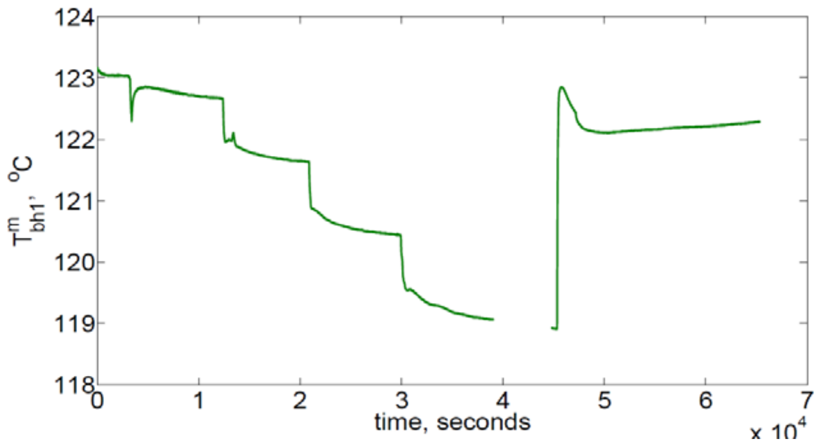
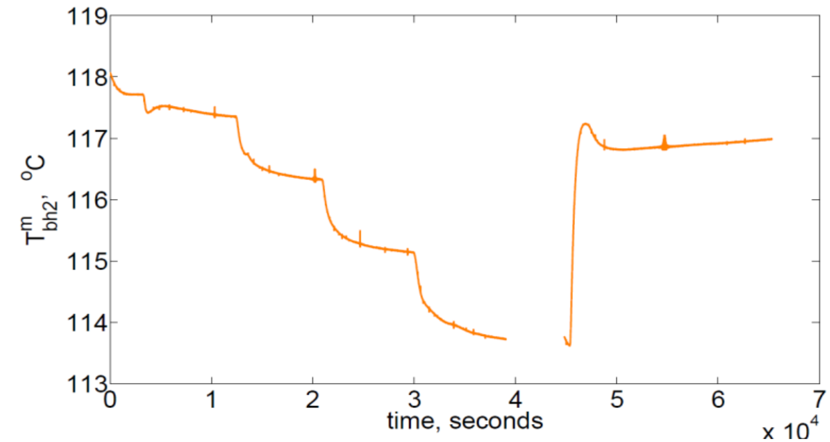
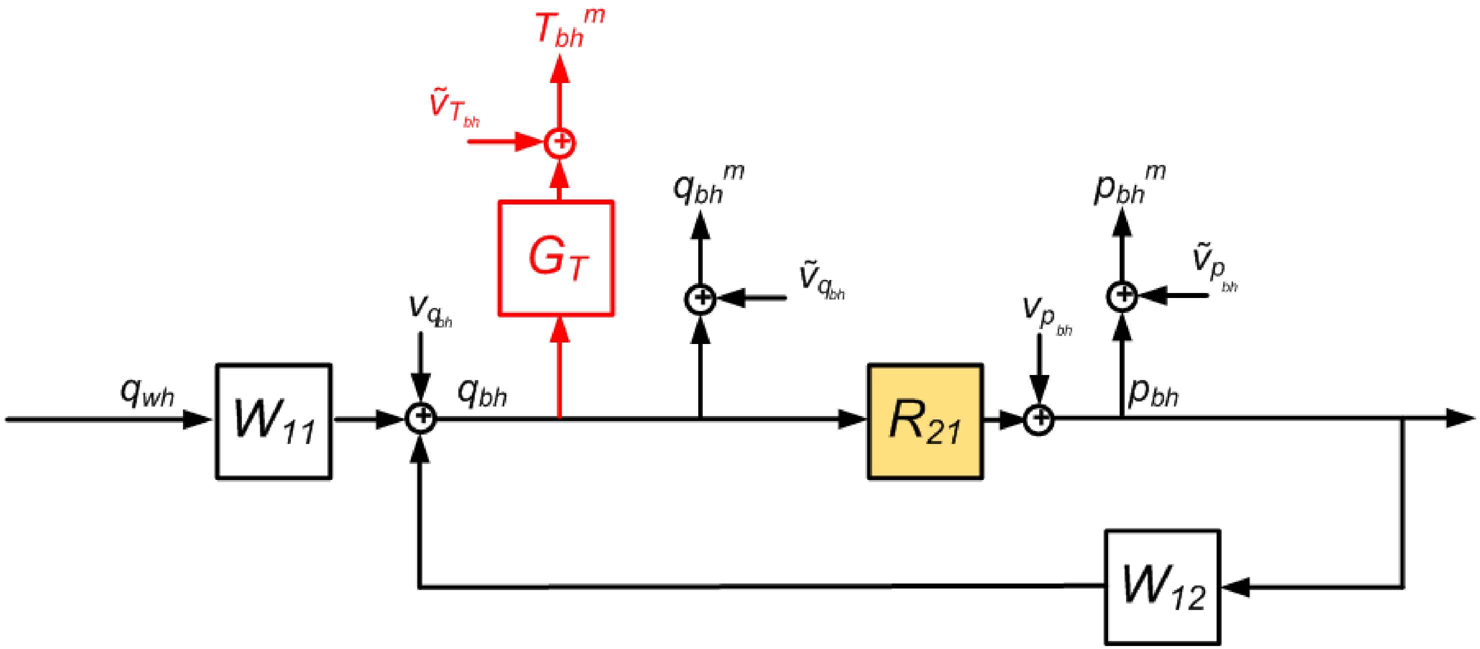




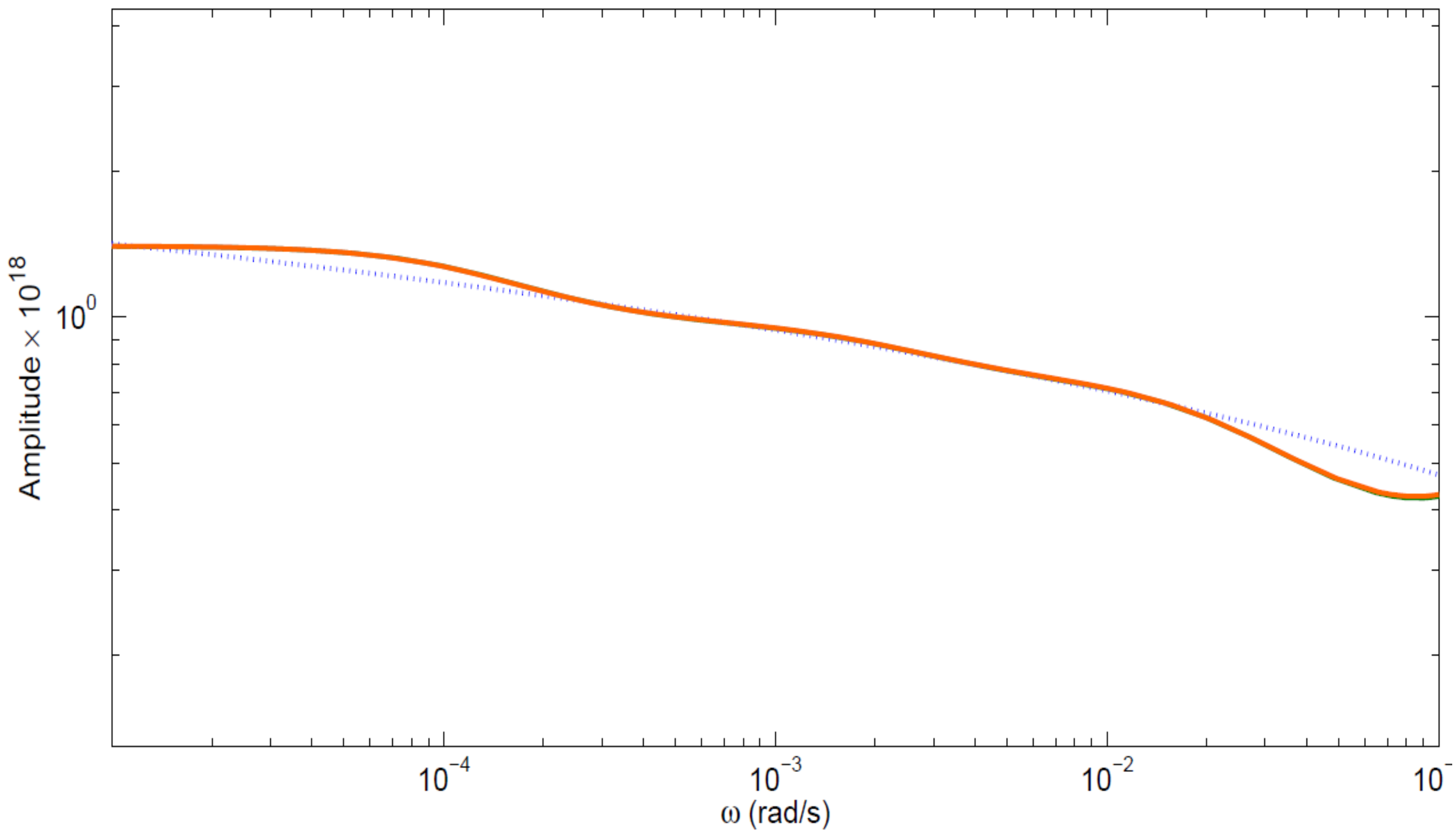




Field data – temperature measurement



Field data – EIVIV Method Results



Physical Parameter Estimation Results

Estimated physical parameters		
	Permeability (mD)	Skin
TS SI	10.6	-2.4
EIVIV	15.8	-1.4
Conventional PTA	11	-2.6

Conclusion

- Bilaterally coupled models increase the insight for the well test problem.
- System identification can effectively solved the well test analysis problem (no need to shut-in)
- The two-stage method can remove the wellbore effect.
- The physical estimation can be done in the frequency-domain in a well-defined way.
- Method can be generalized to treat noise on well-head flow measurements.

Thank you for your attention.