ON THE USE OF THE ADJOINT METHOD TO EVALUATE SENSITIVITIES IN ADSORBED NATURAL GAS STORAGE SYSTEMS

Bruno Galelli Chieregatti, M. Sc.
João de Sá Brasil Lima, Ph.D
Prof. Ernani Vitillo Volpe, Ph.D.
Marcelo Tanaka Hayashi, Ph.D.
Dept. Mechanical Engineering, EP
University of São Paulo, Brazil

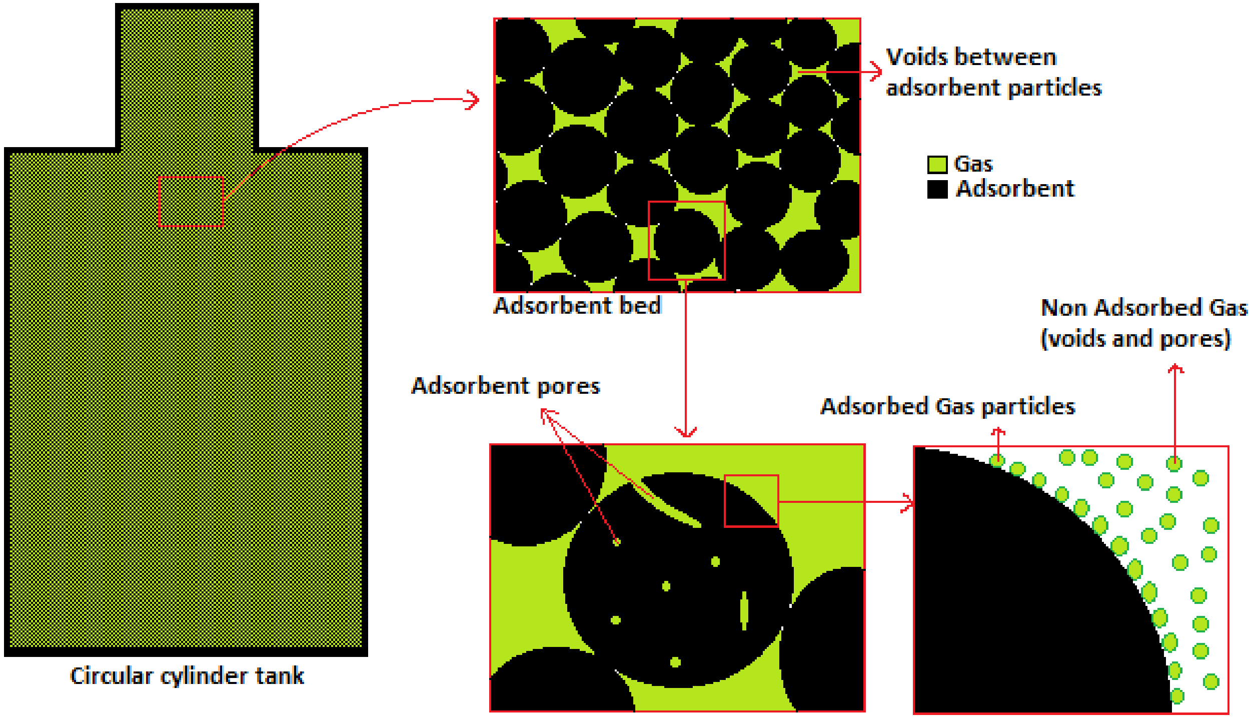
Research Centre for Gas Innovation
cleaner energy for a sustainable future

University of São Paulo

Summary

- Technology Description
- Technology Challenges
- Flow Governing Equations
- Adjoint Method
- Results and Conclusions

Technology Description



Adjoint Solutions

- Converged Solutions

$$A_{\rho 1}\frac{\partial \sigma}{\partial t} + A_{\rho 2}\frac{\partial \Theta}{\partial t} + A_{\rho 3}\nabla.\psi + A_{\rho 4}\nabla\sigma + A_{\rho 5}\Theta = \frac{\delta R}{\delta \rho}$$

$$A_{v1}\psi + A_{v2}\nabla\sigma + A_{v3}\Theta = \frac{\delta R}{\delta v}$$

$$A_{T1}\frac{\partial \sigma}{\partial t} + A_{T2}\frac{\partial \Theta}{\partial t} + A_{T3}\nabla.\psi + A_{T4}\nabla\Theta + A_{T5}\nabla^2\Theta + A_{T6}\Theta = \frac{\delta R}{\delta T}$$

Gradient Validation

- Without Adsorption

$$R = \frac{1}{t}\int_0^t \int_\Omega \epsilon_t \frac{\partial \rho}{\partial t} dV dt \longrightarrow \frac{\delta R}{\delta \rho} = 0, \quad \frac{\delta R}{\delta v} = 0, \quad \frac{\delta R}{\delta T} = 0$$

$$\alpha = G_m$$

Analytical: $\frac{\partial R}{\partial G_m} = 1.267.10^{-3}$

Finite Difference: $\frac{\partial R}{\partial G_m} = 1.267.10^{-3}$

Adjoint: $\frac{\partial R}{\partial G_m} = 1.267.10^{-3}$

Gradient Validation

- Without Adsorption

$$R = \frac{1}{t}\int_0^t \int_\Omega \epsilon_t \rho \, dV dt$$

$$\alpha = G_m$$

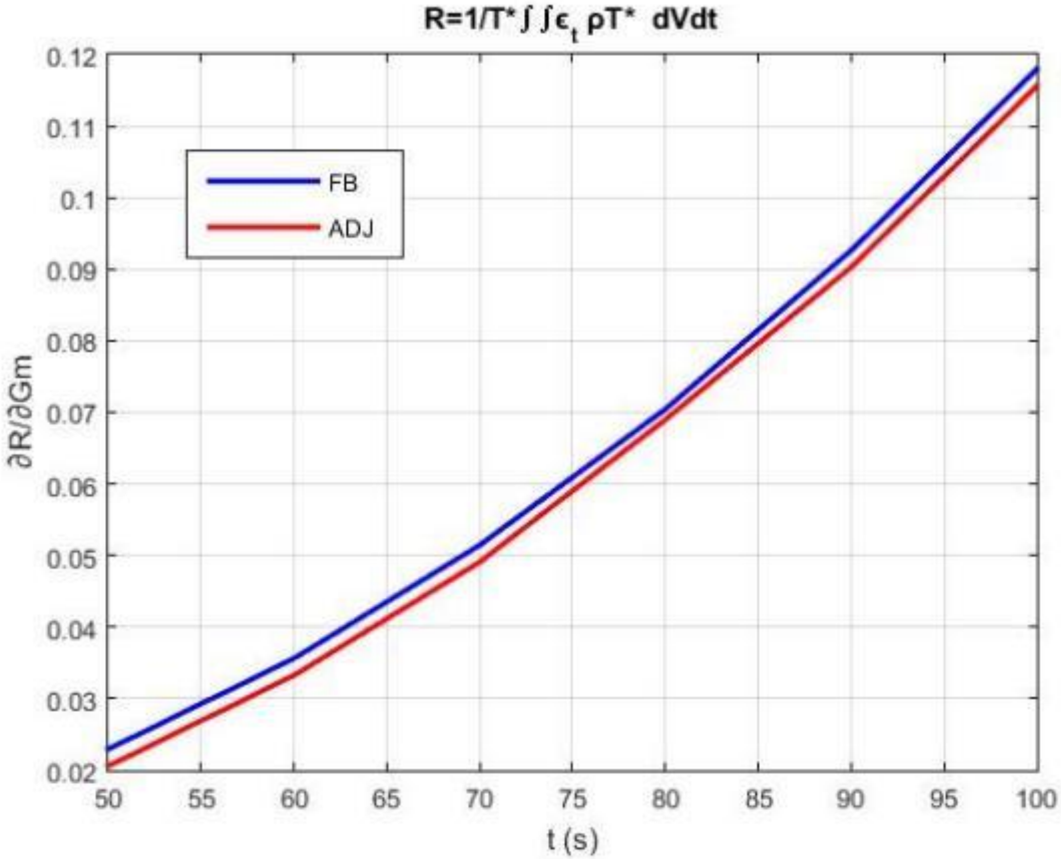
$$\frac{\delta R}{\delta \rho} = \epsilon_t$$

$$\frac{\delta R}{\delta v} = 0$$

$$\frac{\delta R}{\delta T} = 0$$

Gradient Validation

- Without Adsorption



Gradient Validation

- Without Adsorption

$$R = \frac{1}{t}\int_0^t \frac{1}{V_t}\int p \, dV dt$$

$\longrightarrow$

$$\frac{\delta R}{\delta \rho} = \frac{T}{V_t}$$

$$\frac{\delta R}{\delta v} = 0$$

$$\frac{\delta R}{\delta T} = \frac{\rho}{V_t}$$

$$\alpha_1 = G_m$$

$$\alpha_2 = Nu$$

Gradient Validation

$\delta^+ = 10\,min$ $\delta^+ = 10\,min$
$\delta^- = 10\,min$ $\delta^- = 10\,min$

Control Parameters: (G_m, Nu)	$R = \frac{1}{t}\int_0^t \frac{1}{V_t}\int p\, dV dt$					
	$Nu = 23.6636$ $Gm = 11.150 \frac{kg}{m^2 s}$					
t (s)	$\frac{\partial R}{\partial Gm}$			$\frac{\partial R}{\partial Nu}$		
	BF	ADJ	Dif.	BF	ADJ	Dif.
50	0.39997	0.36935	7.65%	-8.418 e-05	-8.372 e-05	0.6%
60	0.52039	0.50397	3.15%	-1.453 e-04	-1.443 e-04	0.7%
70	0.64813	0.64605	0.32%	-2.289 e-04	-2.272 e-04	0.7%
80	0.78094	0.79405	1.68%	-3.386 e-04	-3.368 e-04	0.6%
90	0.91758	NAN	-	-4.750 e-04	NAN	-
100	1.05730	NAN	-	-6.416 e-04	NAN	-

$Flow = 10\,min$
$Adj = 10\,min$

Gradient Validation

- Without Adsorption

$$R = \frac{1}{t}\int_0^t \frac{1}{V_t}\int T\, dV dt \longrightarrow \frac{\delta R}{\delta \rho} = 0,\quad \frac{\delta R}{\delta v} = 0,\quad \frac{\delta R}{\delta T} = \frac{1}{V_t}$$

$$\alpha_1 = G_m$$
$$\alpha_2 = Nu$$

Gradient Validation

$\delta^+ = 10\,min$ $\delta^+ = 10\,min$
$\delta^- = 10\,min$ $\delta^- = 10\,min$

Control Parameters: (G_m, Nu)	$R = \frac{1}{t}\int_0^t \frac{1}{V_t}\int T\,dV dt$					
	$Nu = 23.6636$ $Gm = 11.150 \frac{kg}{m^2 s}$					
t (s)	$\frac{\partial R}{\partial Gm}$			$\frac{\partial R}{\partial Nu}$		
	BF	ADJ	Dif.	BF	ADJ	Dif.
50	4.020 e-04	1.314 e-03	126%	-8.784 e-06	-8.756 e-06	0.4%
60	5.123 e-04	1.752 e-03	142%	-1.128 e-05	-1.126 e-05	0.4%
70	6.252 e-04	2.200 e-03	151%	-1.411 e-05	-1.406 e-05	0.5%
80	7.384 e-04	2.646 e-03	158%	-1.721 e-05	-1.711 e-05	0.6%
90	8.509 e-04	NAN	-	-2.060 e-05	NAN	-
100	9.618 e-04	NAN	-	-2.424 e-05	NAN	-

$Flow = 10\,min$
$Adj = 10\,min$

Gradient Validation

- With Adsorption

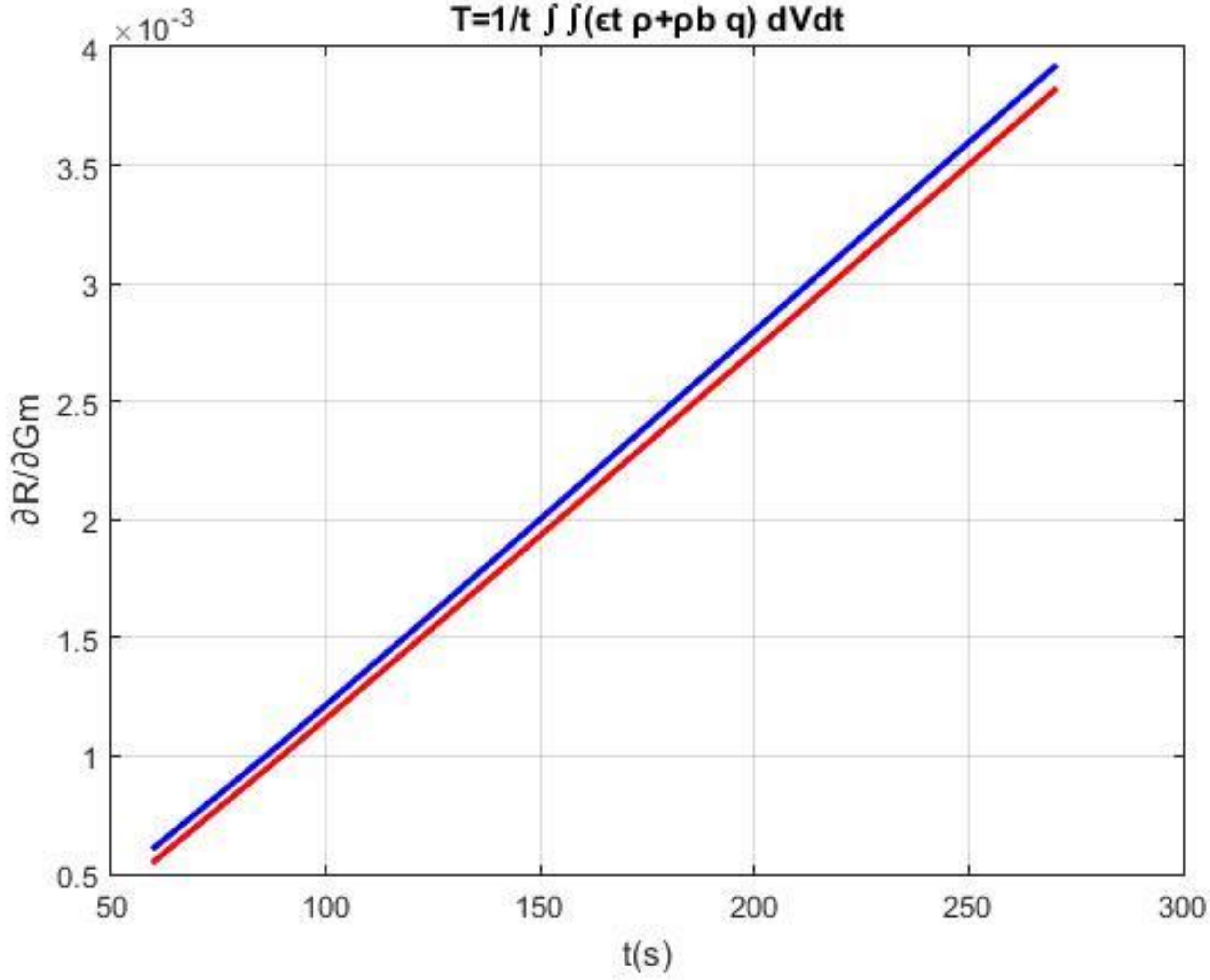
$$\frac{\delta R}{\delta \rho} = (\epsilon_t + \rho_b A_\rho)$$

$$R = \frac{1}{t}\int_0^t \int (\epsilon_t \rho + \rho_b q)\, dV dt \longrightarrow \frac{\delta R}{\delta v} = 0$$

$$\frac{\delta R}{\delta T} = \rho_b A_T$$

$$\alpha_1 = G_m$$

Gradient Validation



Acomplishments and Next Steps

- Bibliography survey : ✓
- Understanding of the flow physics : ✓
- Development of a flow solver: ✓
- Exploratory Simulations to identify optimizations possibilities: ✓
- Derivation of Adjoint Equations applied in flow through porous media: ✓
- Gradient Validation: **Working on it**

Centro de Pesquisa para Inovação em Gás

cleaner energy for a sustainable future

THANK YOU

facebook.com/GasInnovation

twitter.com/rcgipage

www.usp.br/rcgi