FIG. 1

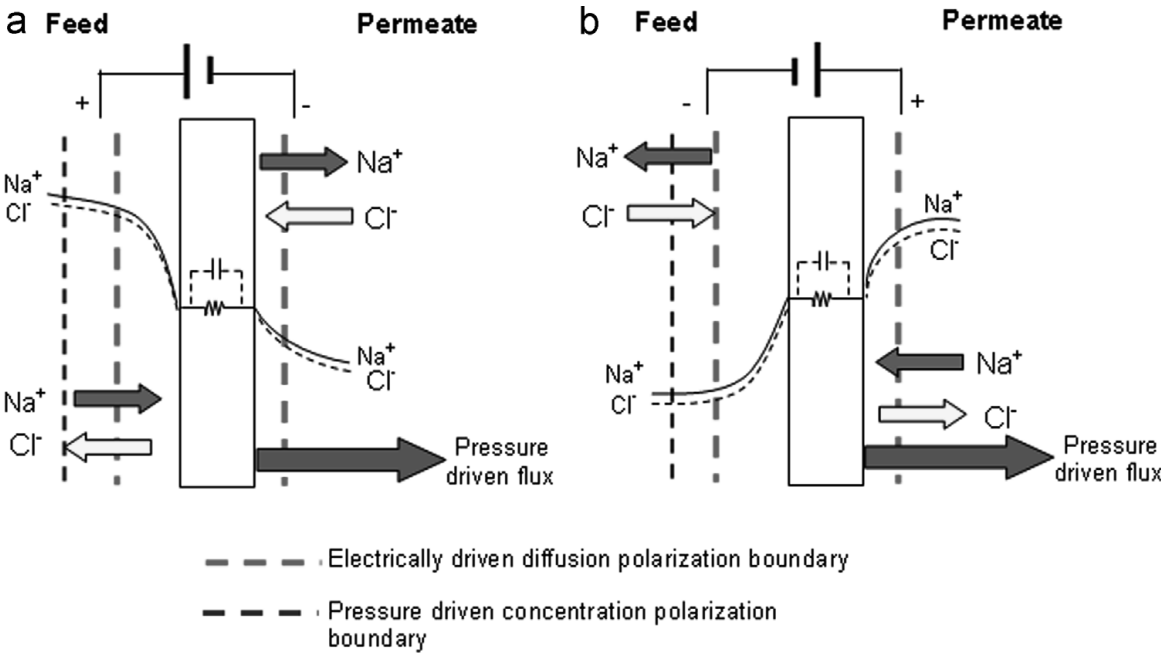

a
Feed
Permeate
+
-
Na+
Cl-
Na+
Cl-
Na+
Cl-
Na+
Cl-
Pressure driven flux
b
Feed
Permeate
-
+
Na+
Cl-
Na+
Cl-
Na+
Cl-
Na+
Cl-
Pressure driven flux
Electrically driven diffusion polarization boundary
Pressure driven concentration polarization boundary

FIG. 2

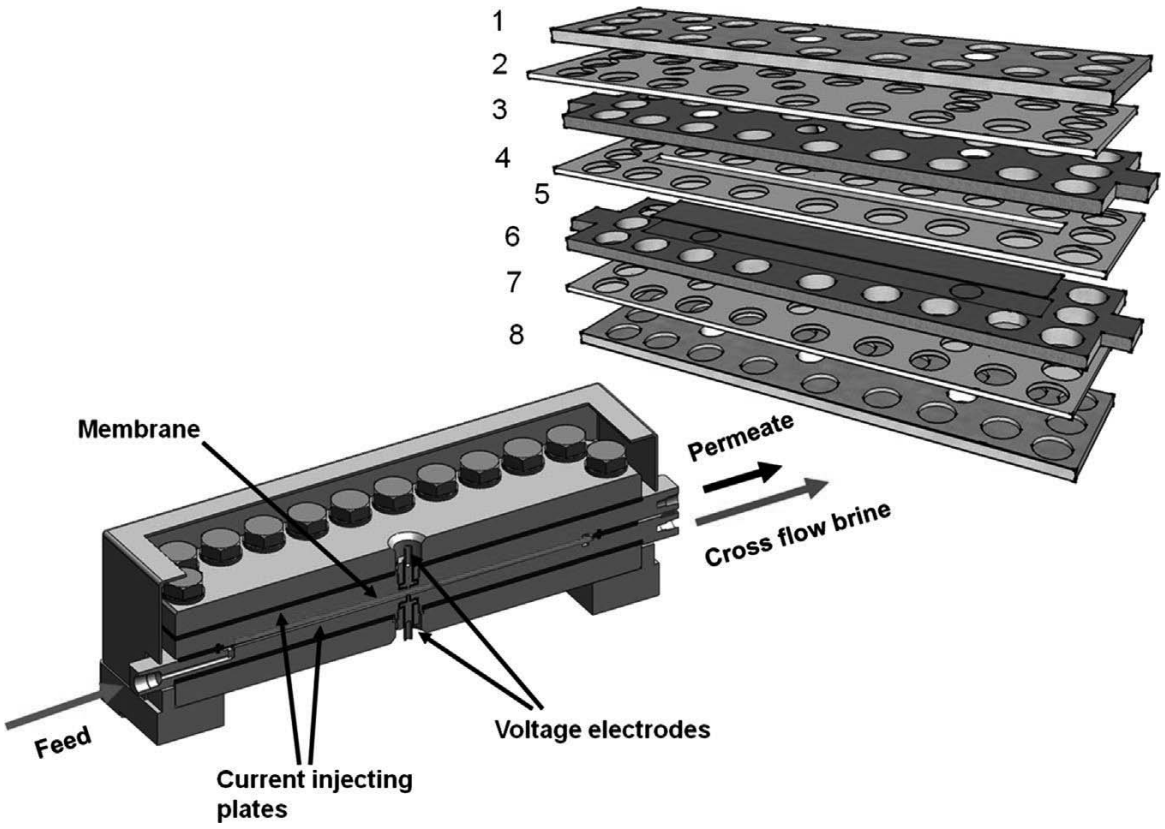

1
2
3
4
5
6
7
8
Membrane
Permeate
Cross flow brine
Feed
Current injecting plates
Voltage electrodes

FIG. 3

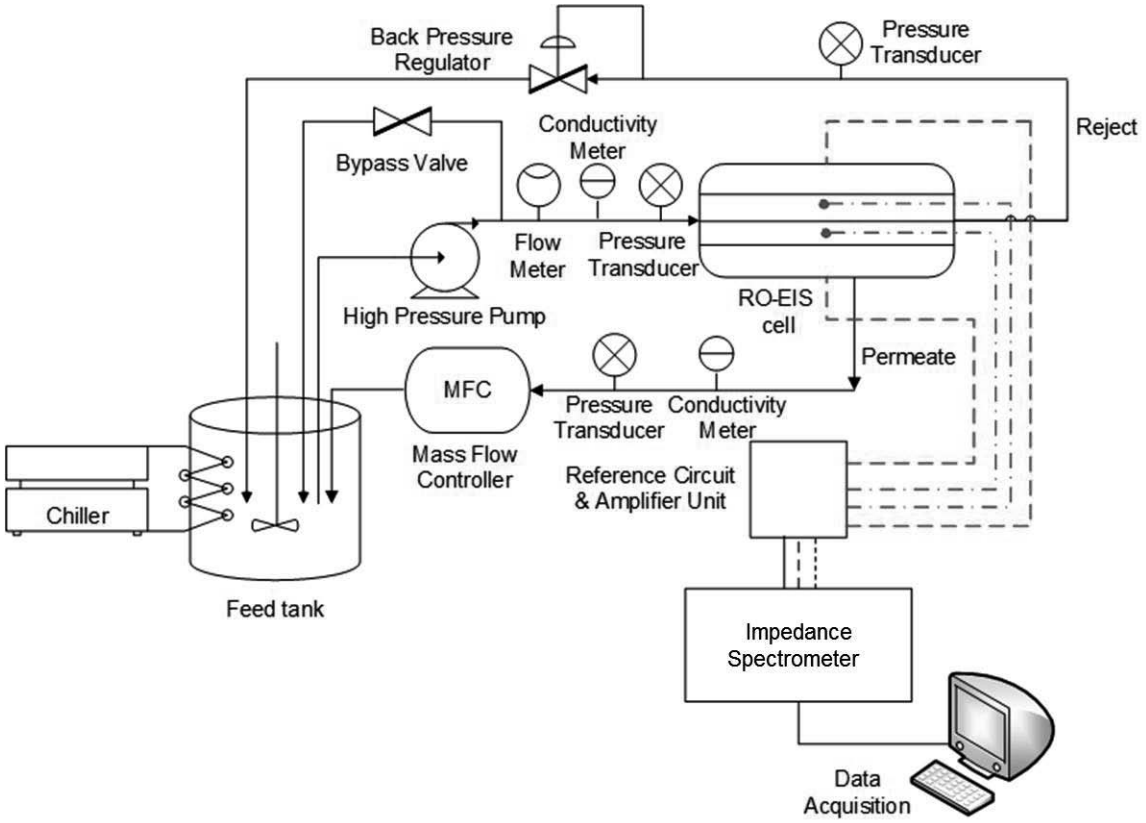

Back Pressure Regulator
Pressure Transducer
Reject
Conductivity Meter
Bypass Valve
Flow Meter
Pressure Transducer
RO-EIS cell
High Pressure Pump
Permeate
MFC
Pressure Transducer
Conductivity Meter
Mass Flow Controller
Reference Circuit & Amplifier Unit
Chiller
Feed tank
Impedance Spectrometer
Data Acquisition

FIG. 4

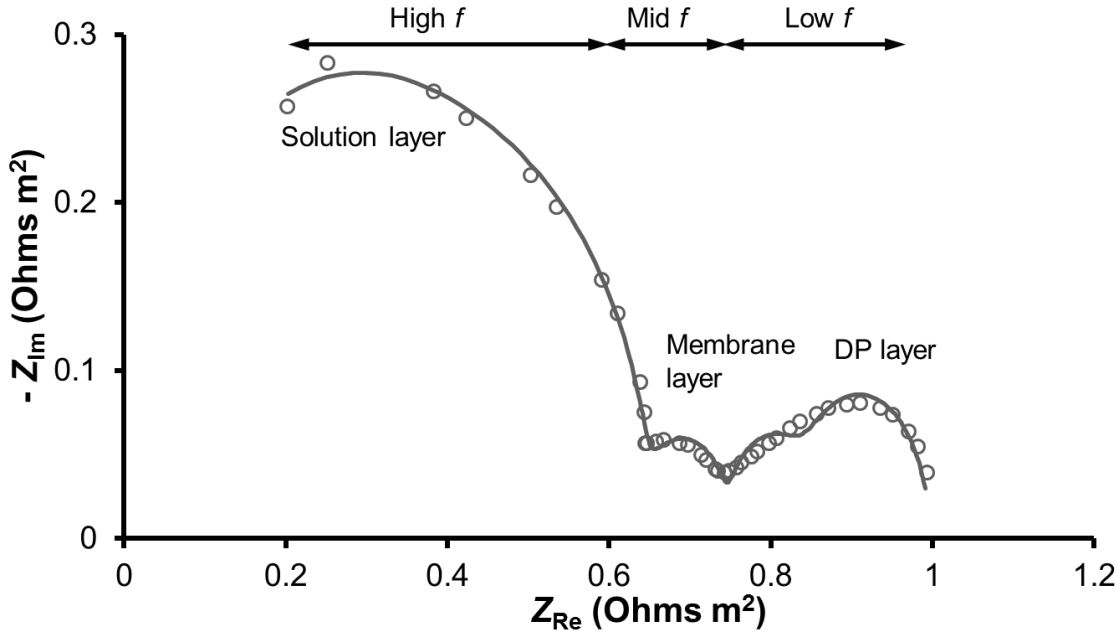

High f
Mid f
Low f
Solution layer
Membrane layer
DP layer
- Z_Im (Ohms m²)
Z_Re (Ohms m²)
0
0.1
0.2
0.3
0.4
0.6
0.8
1
1.2

FIG. 5

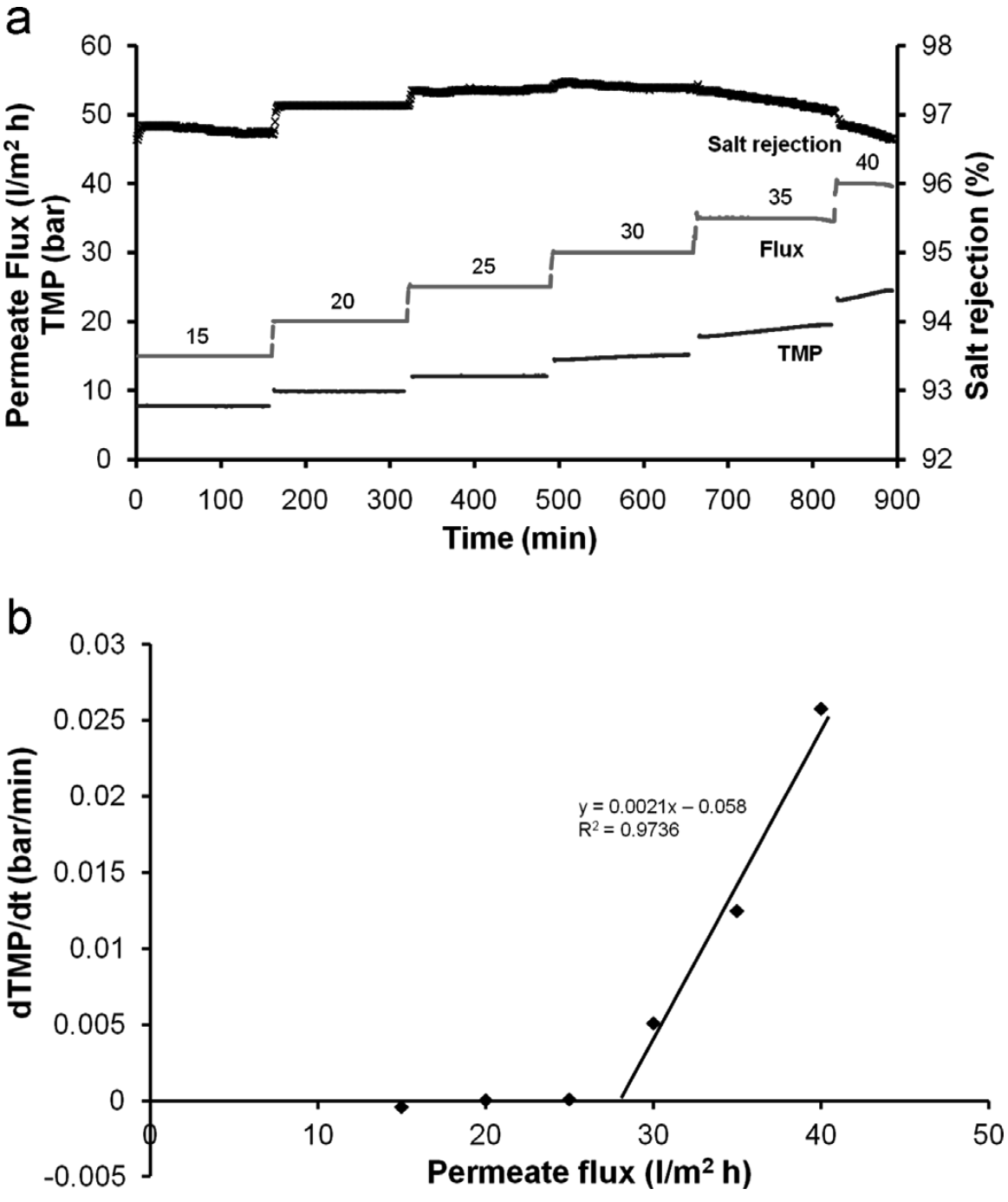

a
Permeate Flux (l/m² h)
TMP (bar)
Salt rejection (%)
Time (min)
Salt rejection
Flux
TMP
15
20
25
30
35
40
b
dTMP/dt (bar/min)
Permeate flux (l/m² h)
y = 0.0021x – 0.058
R² = 0.9736

FIG. 6

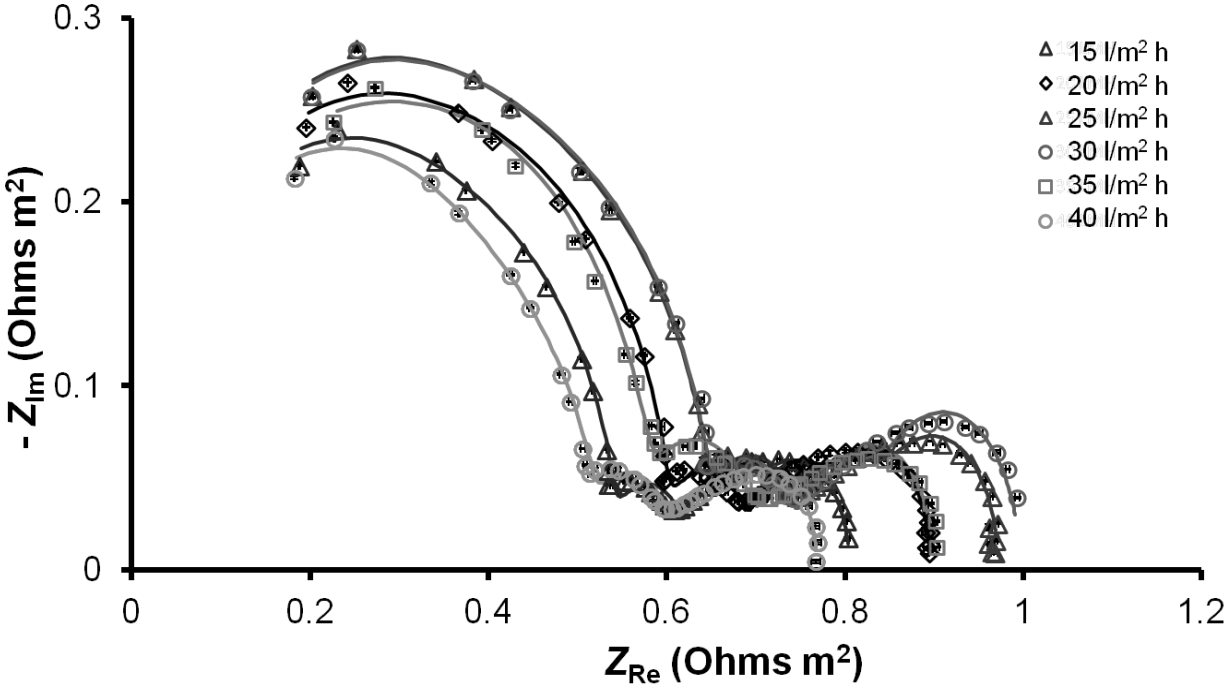

0.3
0.2
0.1
0
- Z_Im (Ohms m²)
0
0.2
0.4
0.6
0.8
1
1.2
Z_Re (Ohms m²)
15 l/m² h
20 l/m² h
25 l/m² h
30 l/m² h
35 l/m² h
40 l/m² h

FIG. 7

(A)

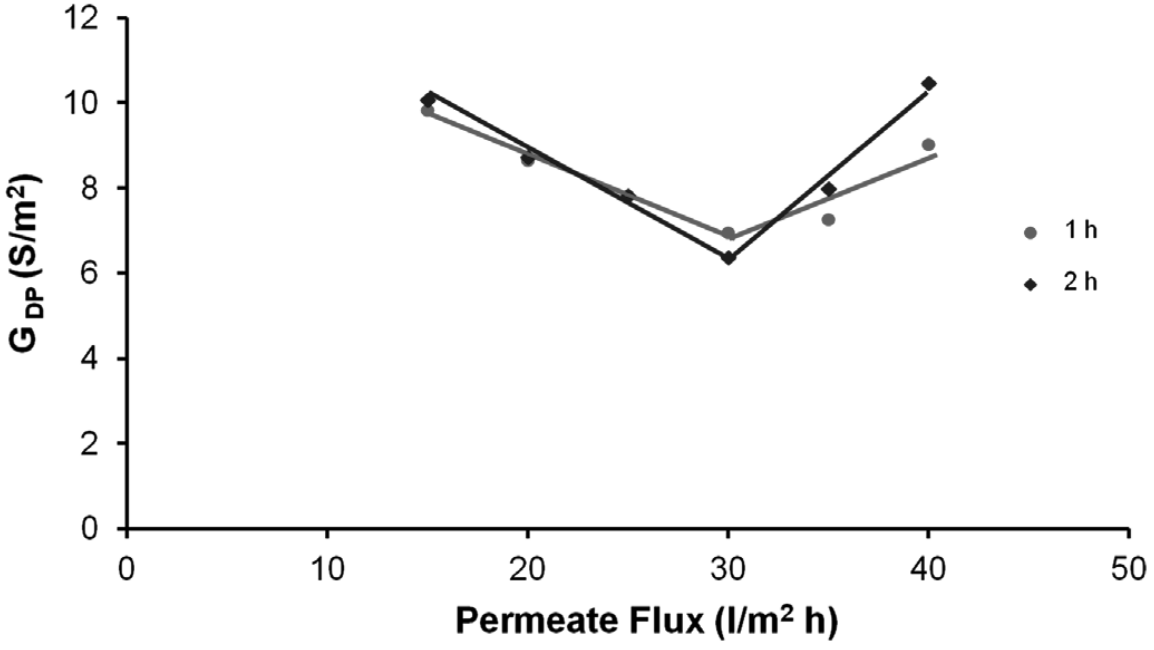
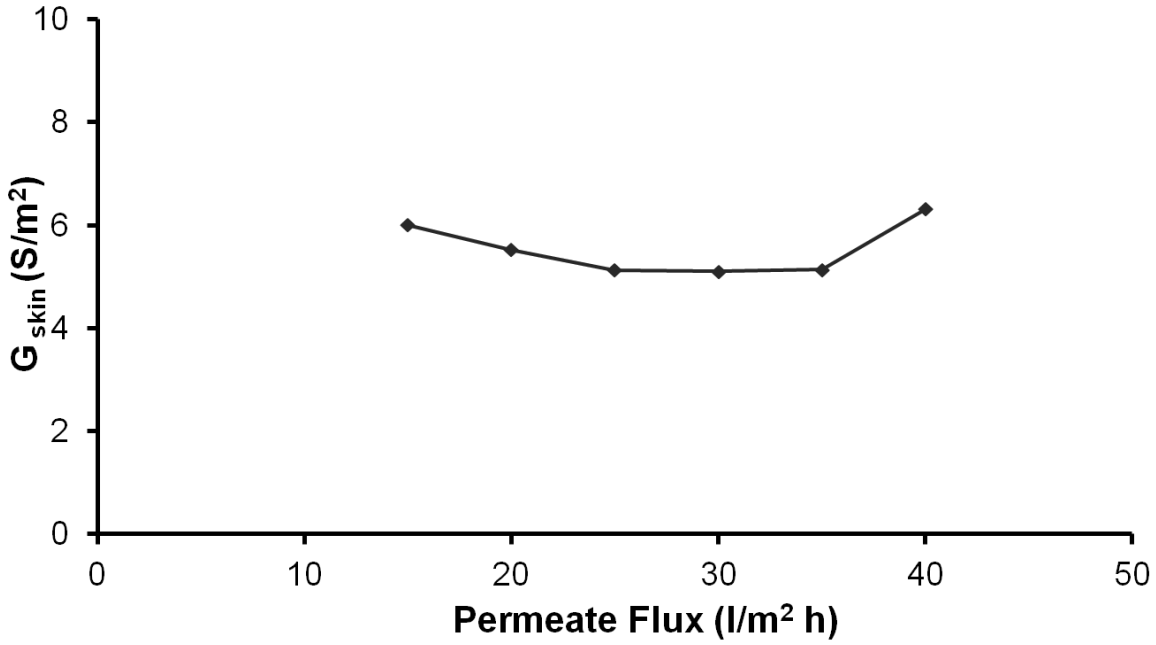

12
10
8
6
4
2
0
G_DP (S/m²)
0
10
20
30
40
50
Permeate Flux (l/m² h)
1 h
2 h

FIG. 7 (Cont.)

(B)


10
8
6
4
2
0
G_{skin} (S/m²)
0
10
20
30
40
50
Permeate Flux (l/m² h)

(C)

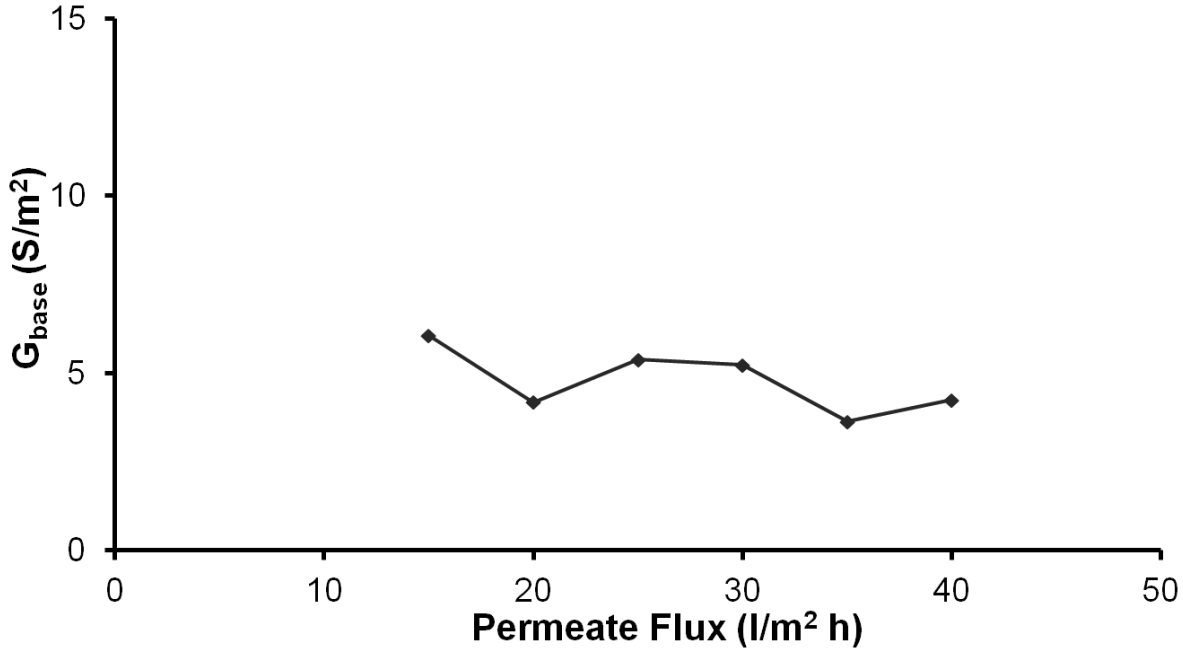

15
10
5
0
G_{base} (S/m²)
0
10
20
30
40
50
Permeate Flux (l/m² h)

FIG. 8

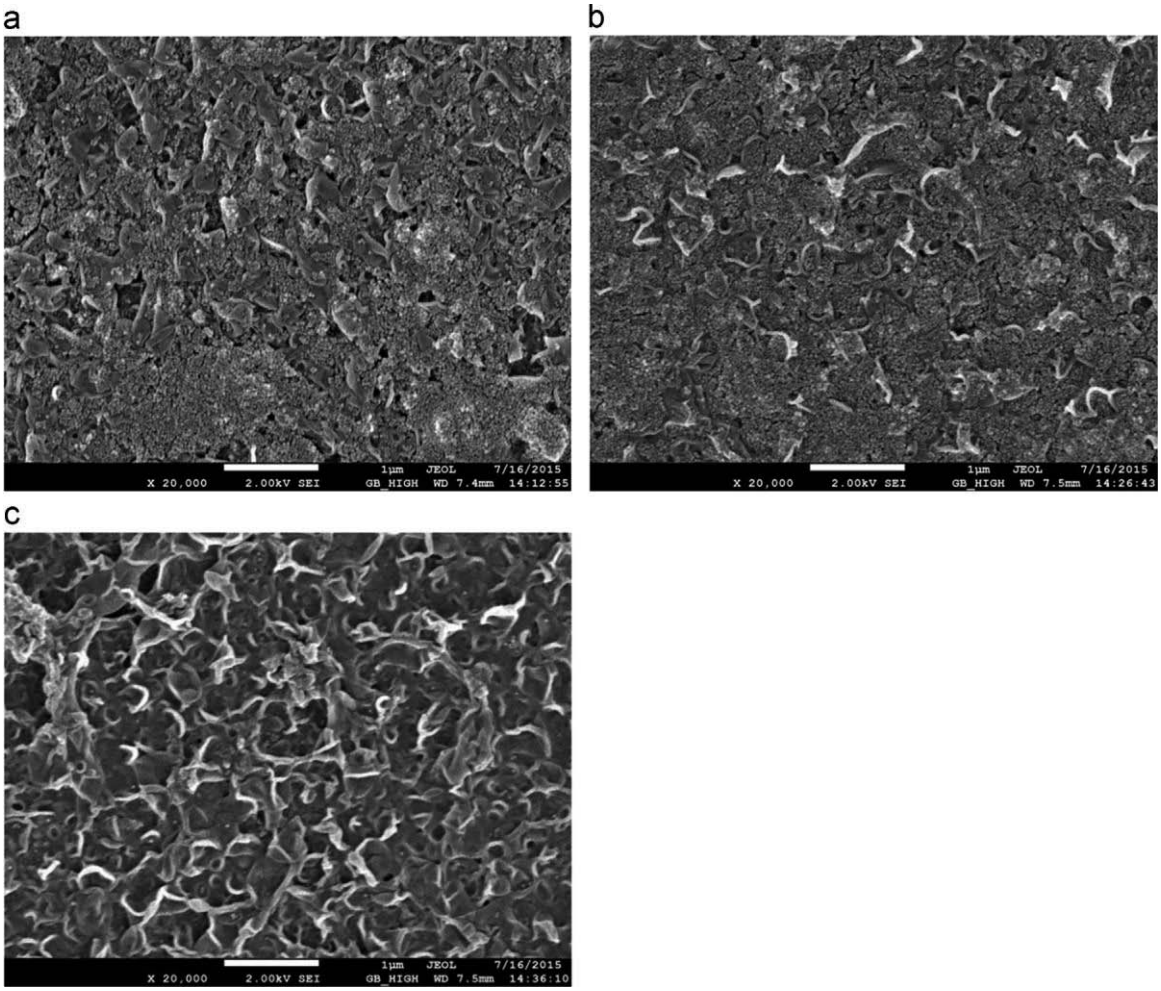

a
X 20,000 2.00kV SEI 1μm JEOL 7/16/2015 GB_HIGH WD 7.4mm 14:12:55
b
X 20,000 2.00kV SEI 1μm JEOL 7/16/2015 GB_HIGH WD 7.5mm 14:26:43
c
X 20,000 2.00kV SEI 1μm JEOL 7/16/2015 GB_HIGH WD 7.5mm 14:36:10

FIG. 9

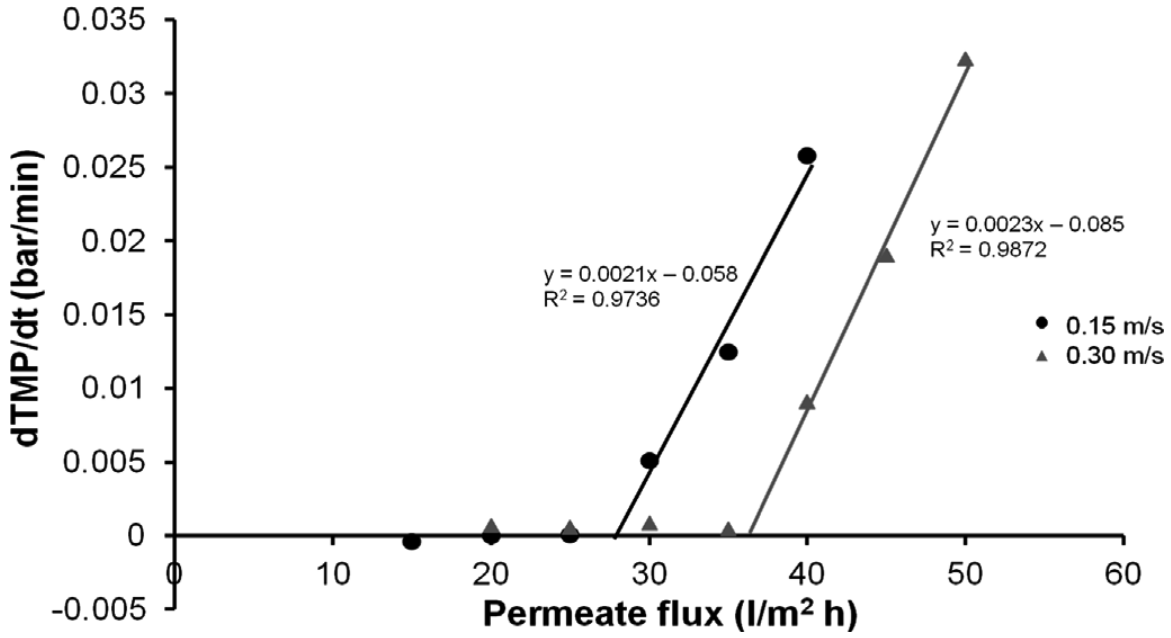

0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
dTMP/dt (bar/min)
0
10
20
30
40
50
60
Permeate flux (l/m² h)
y = 0.0021x – 0.058
R² = 0.9736
y = 0.0023x – 0.085
R² = 0.9872
0.15 m/s
0.30 m/s

FIG. 10

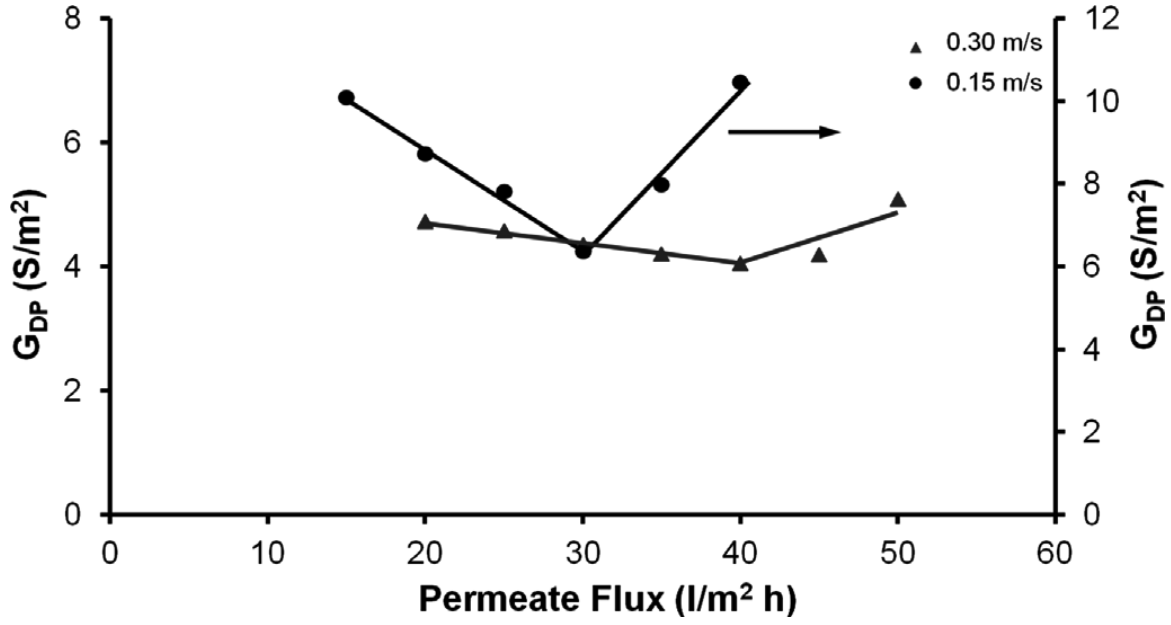

8
6
4
2
0
G_DP (S/m²)
12
10
8
6
4
2
0
G_DP (S/m²)
0
10
20
30
40
50
60
Permeate Flux (l/m² h)
0.30 m/s
0.15 m/s

FIG. 11

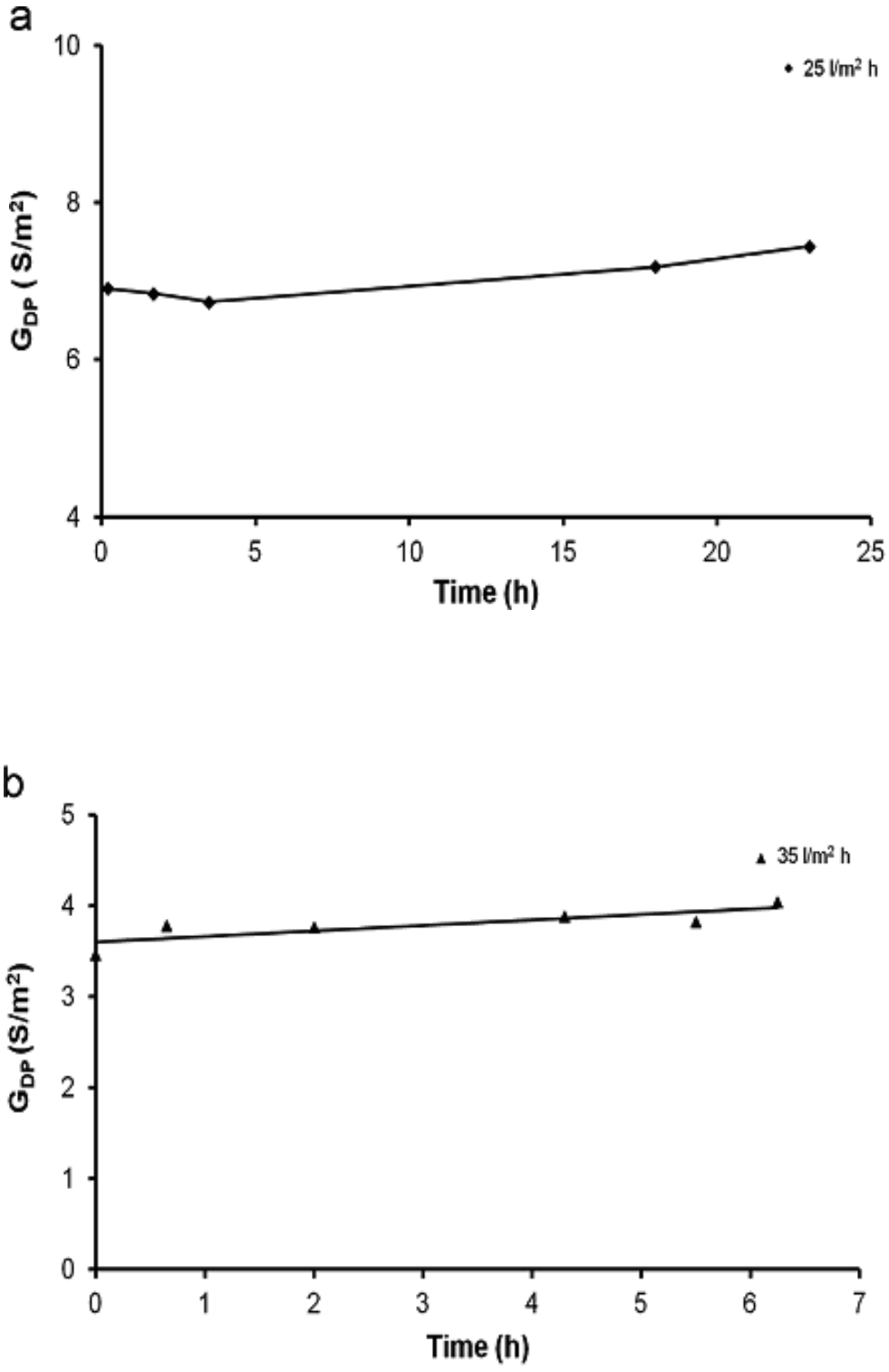

a
10
8
6
4
G_{DP} (S/m²)
25 l/m² h
0
5
10
15
20
25
Time (h)
b
5
4
3
2
1
0
G_{DP}(S/m²)
35 l/m² h
0
1
2
3
4
5
6
7
Time (h)

FIG. 11 (Cont.)

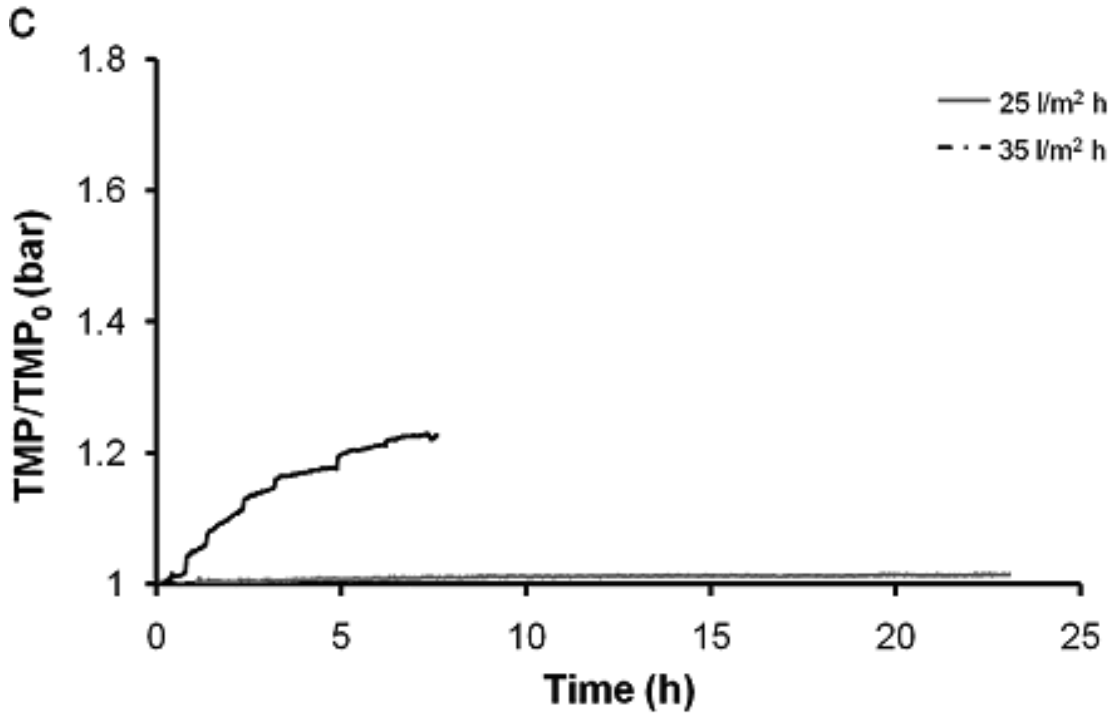


FIG. 12

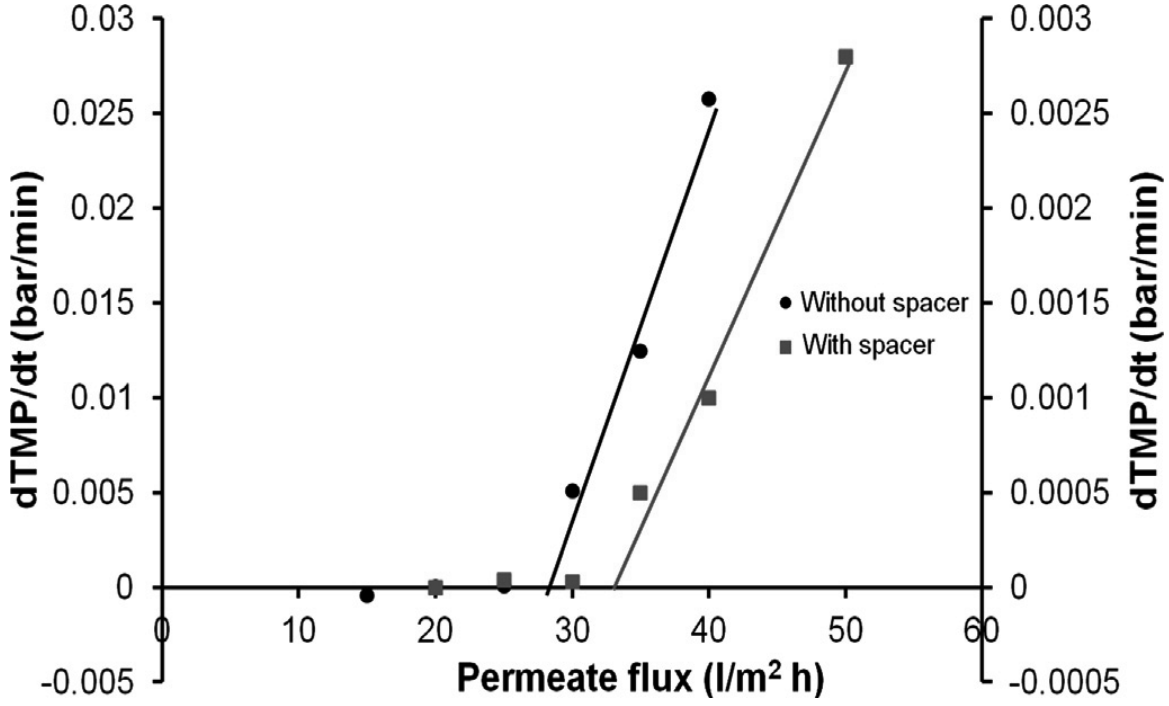


FIG. 13

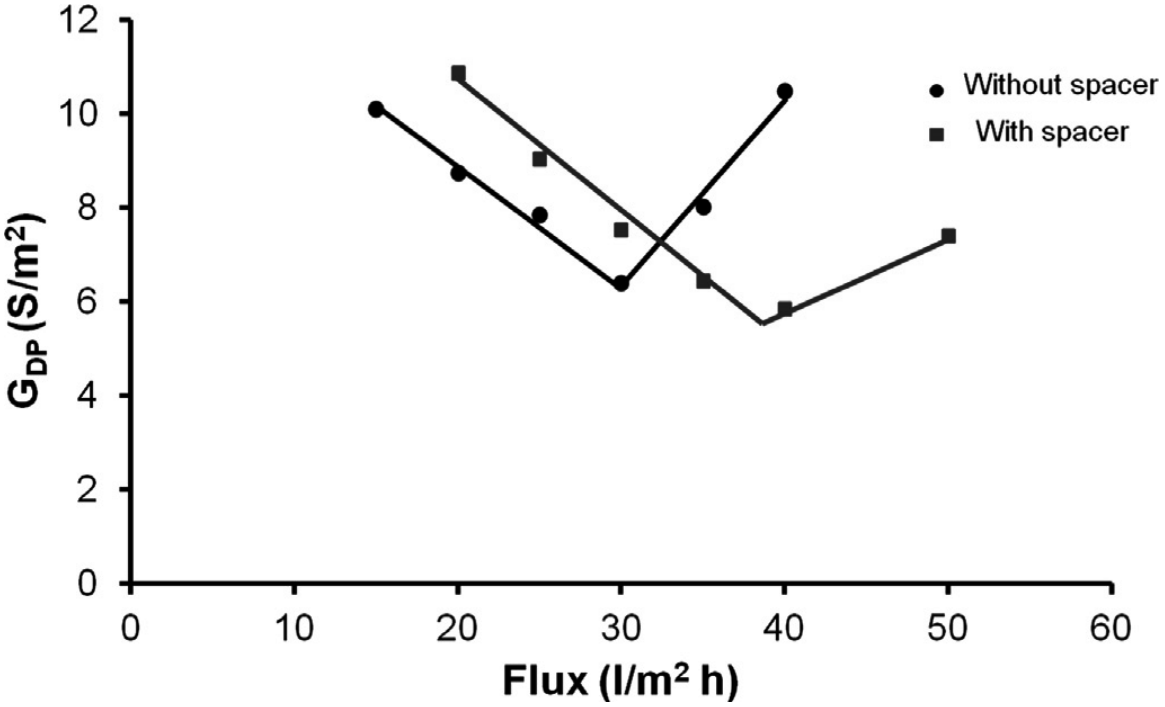

12
10
8
6
4
2
0
G_{DP} (S/m²)
0
10
20
30
40
50
60
Flux (l/m² h)
Without spacer
With spacer

FIG. 14

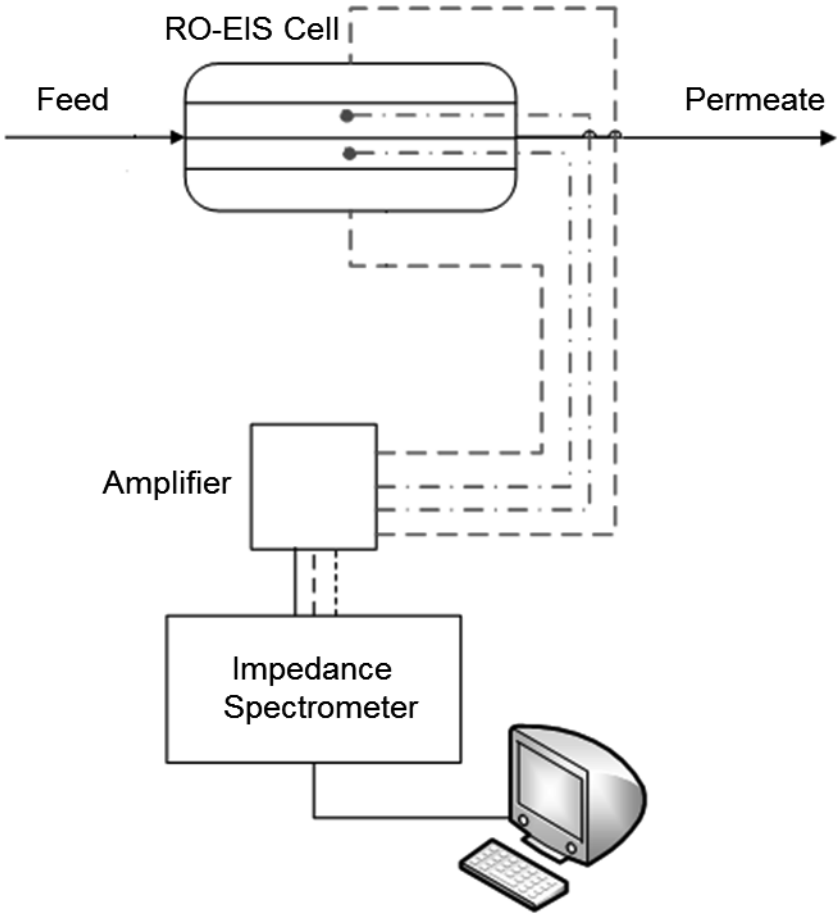

RO-EIS Cell
Feed
Permeate
Amplifier
Impedance
Spectrometer

FIG. 15

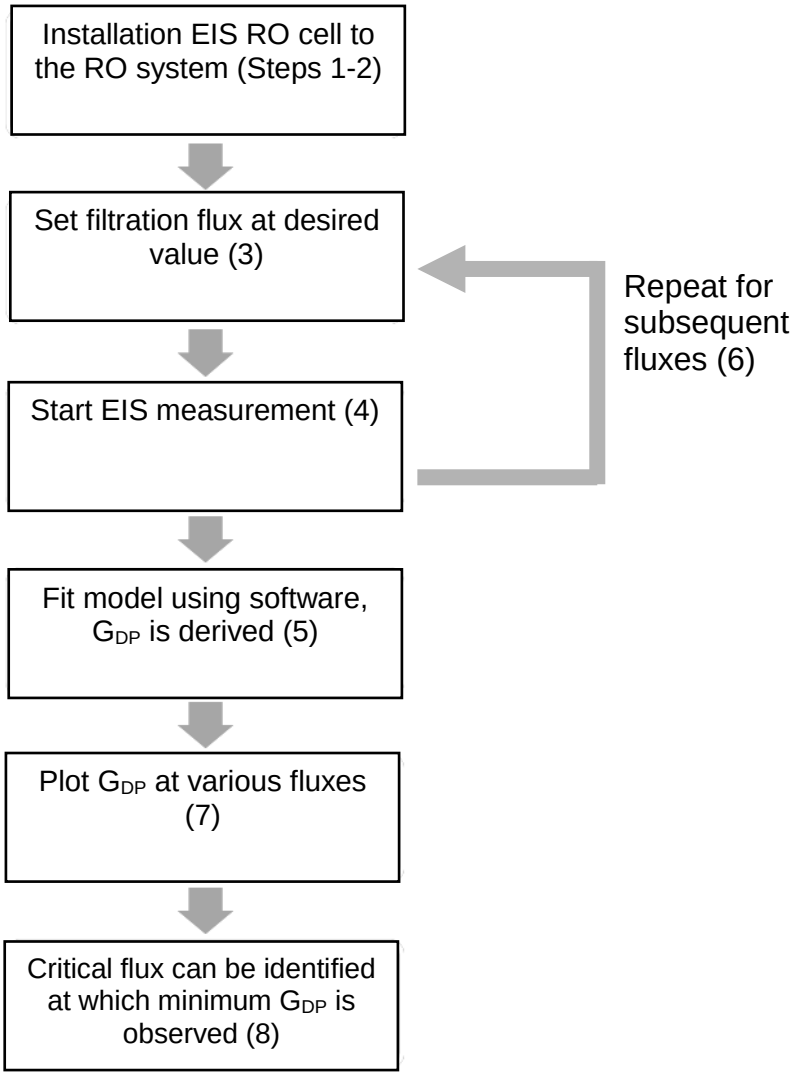

Installation EIS RO cell to the RO system (Steps 1-2)
Set filtration flux at desired value (3)
Start EIS measurement (4)
Repeat for subsequent fluxes (6)
Fit model using software, G_{DP} is derived (5)
Plot G_{DP} at various fluxes (7)
Critical flux can be identified at which minimum G_{DP} is observed (8)

FIG. 16

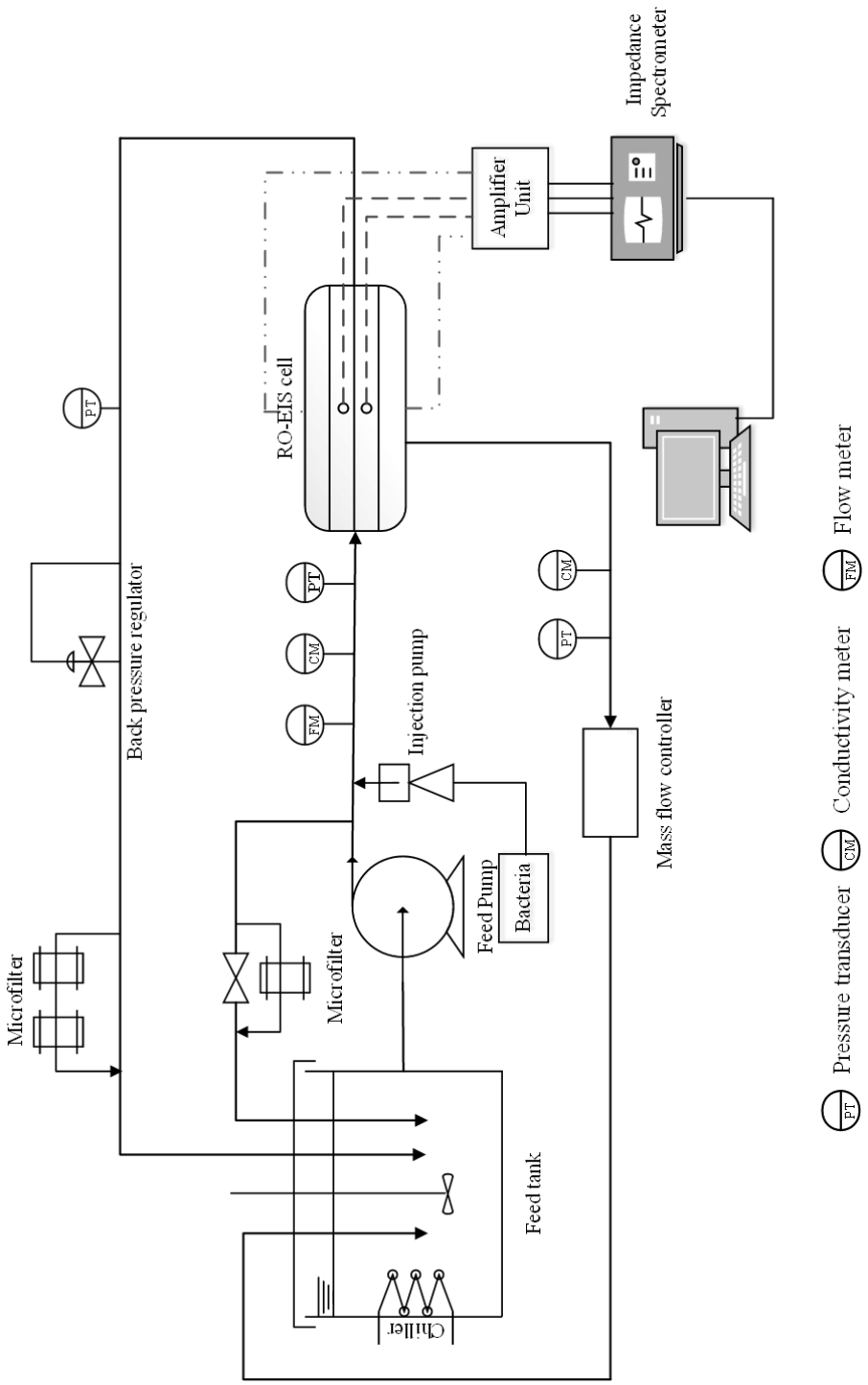

Impedance Spectrometer
Amplifier Unit
RO-EIS cell
PT
Back pressure regulator
Microfilter
Microfilter
Injection pump
Feed Pump
Bacteria
Feed tank
Chiller
Mass flow controller
Pressure transducer
Conductivity meter
Flow meter

FIG. 17

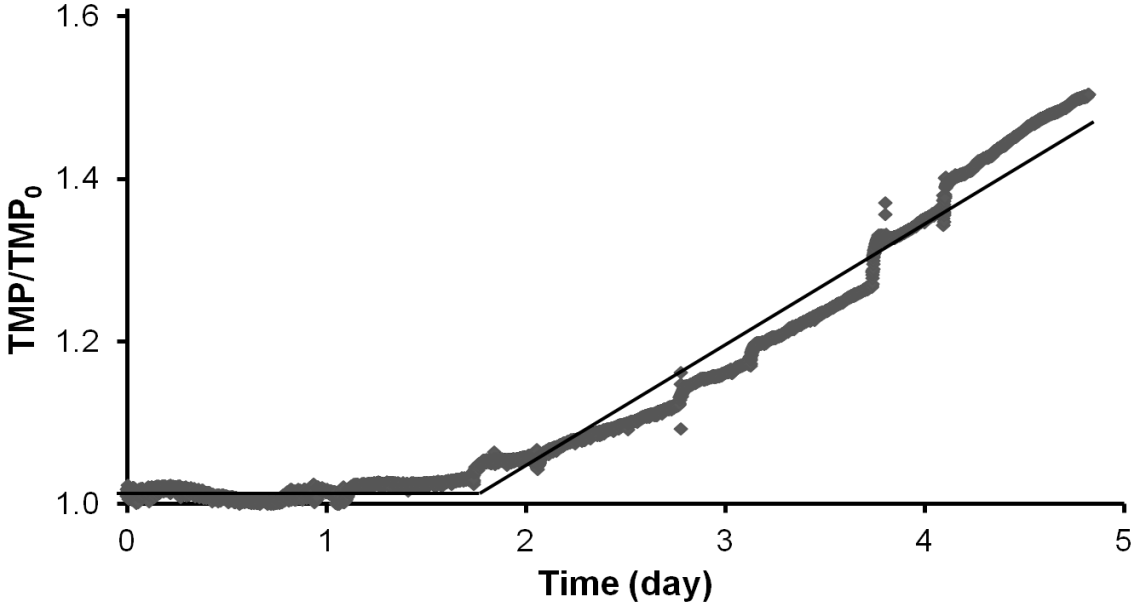

1.6
1.4
1.2
1.0
TMP/TMP0
0
1
2
3
4
5
Time (day)

FIG. 18

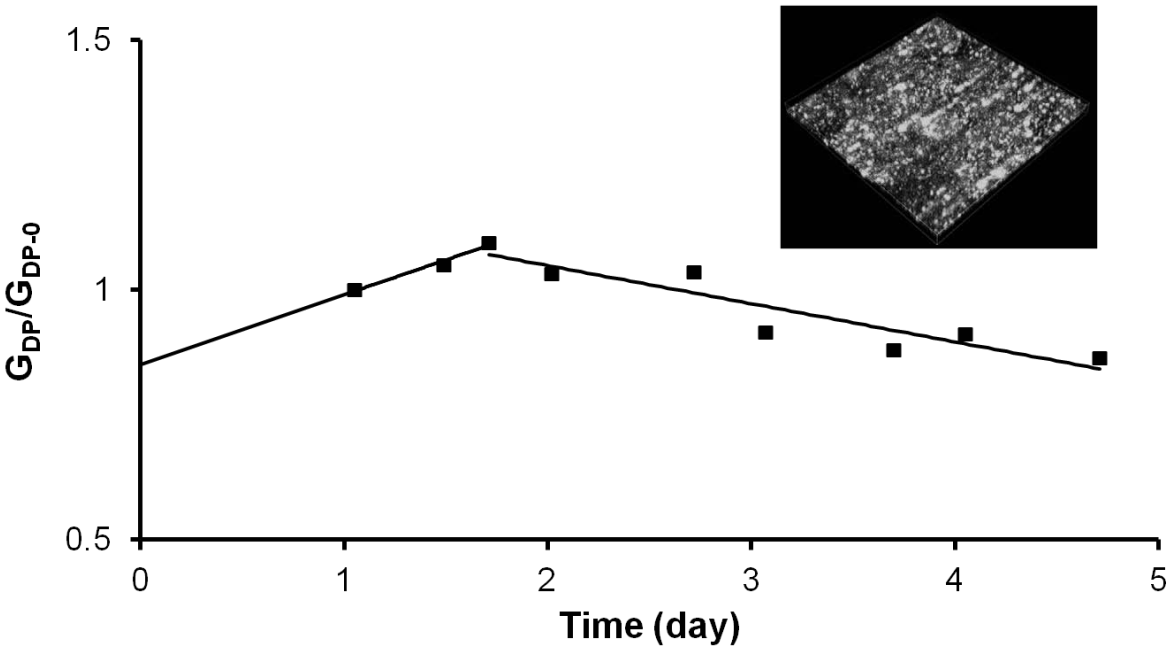

1.5
1
0.5
GDP/GDP-0
0
1
2
3
4
5
Time (day)

FIG. 19

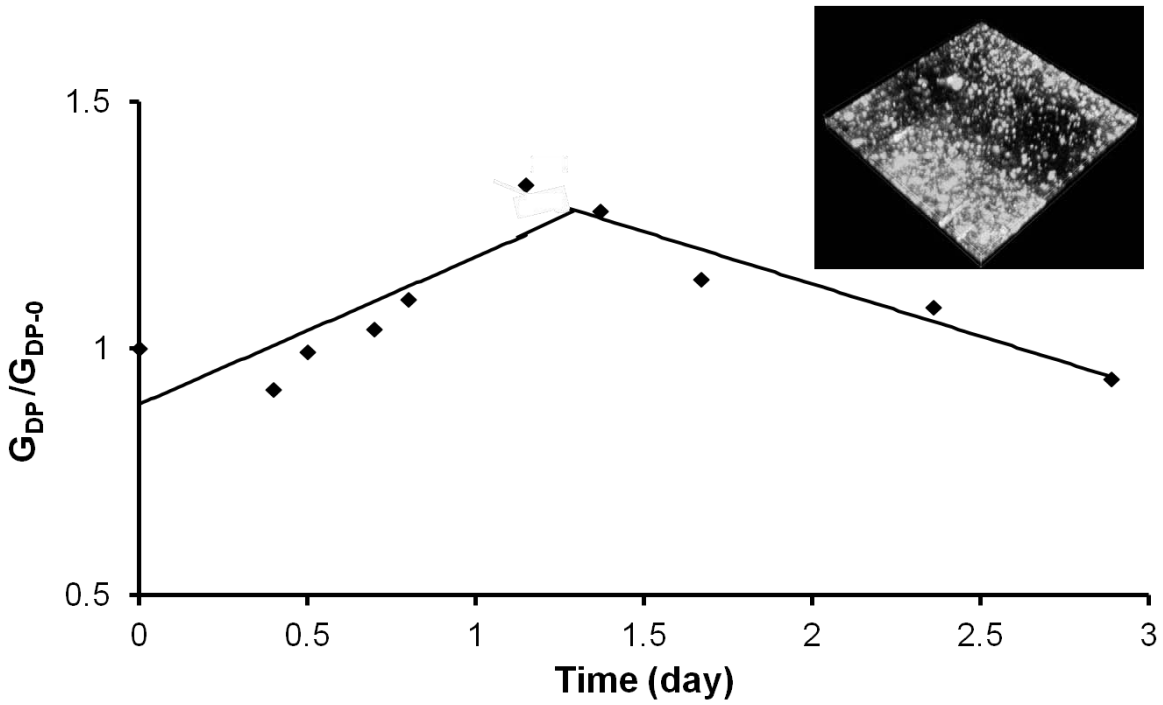

1.5
1
0.5
G_{DP}/G_{DP-0}
0
0.5
1
1.5
2
2.5
3
Time (day)

FIG. 20

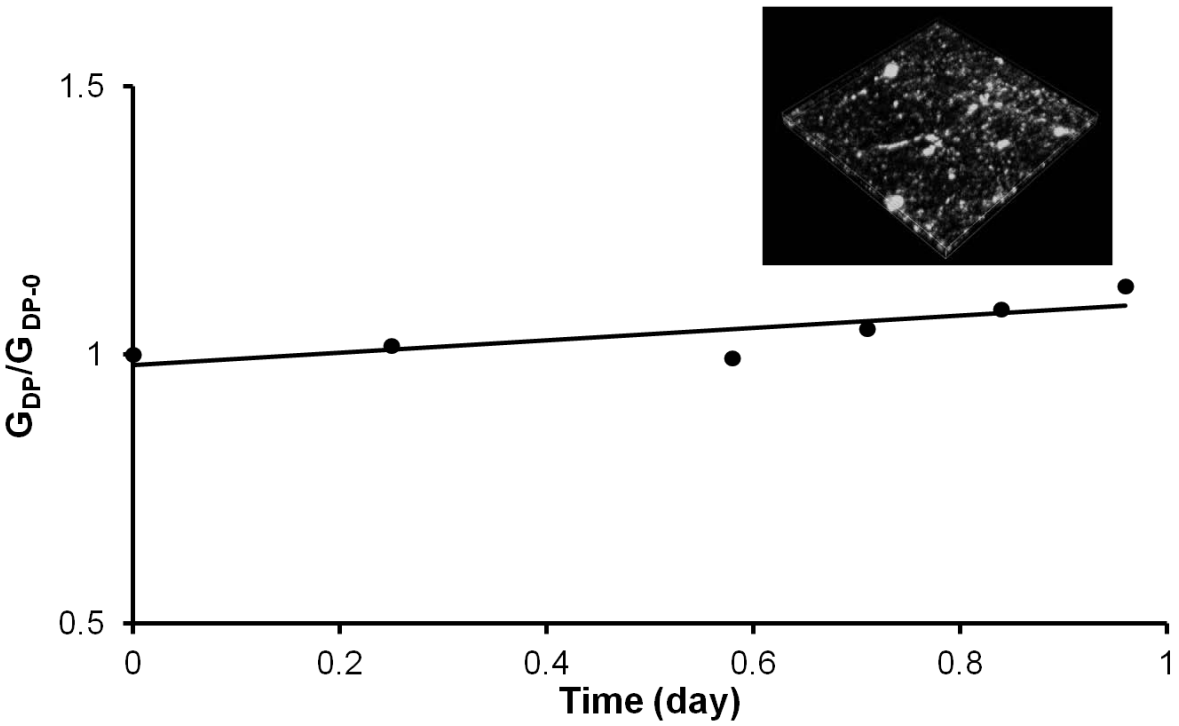

1.5
1
0.5
G_{DP}/G_{DP-0}
0
0.2
0.4
0.6
0.8
1
Time (day)

FIG. 21

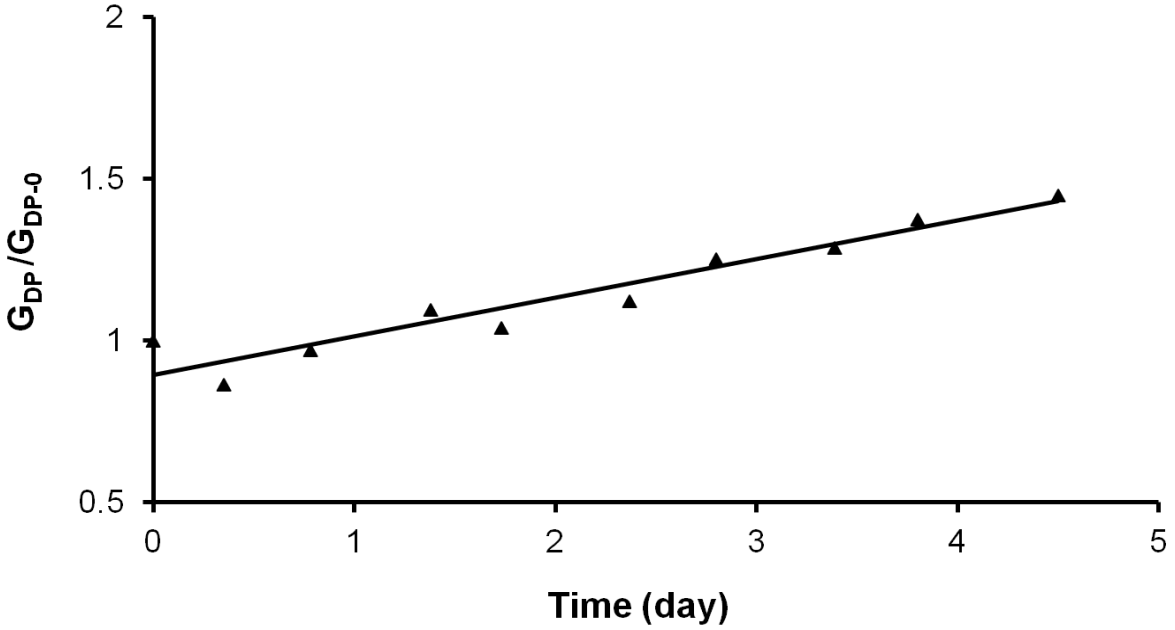

2
1.5
1
0.5
G_{DP}/G_{DP-0}
0
1
2
3
4
5
Time (day)

FIG. 22

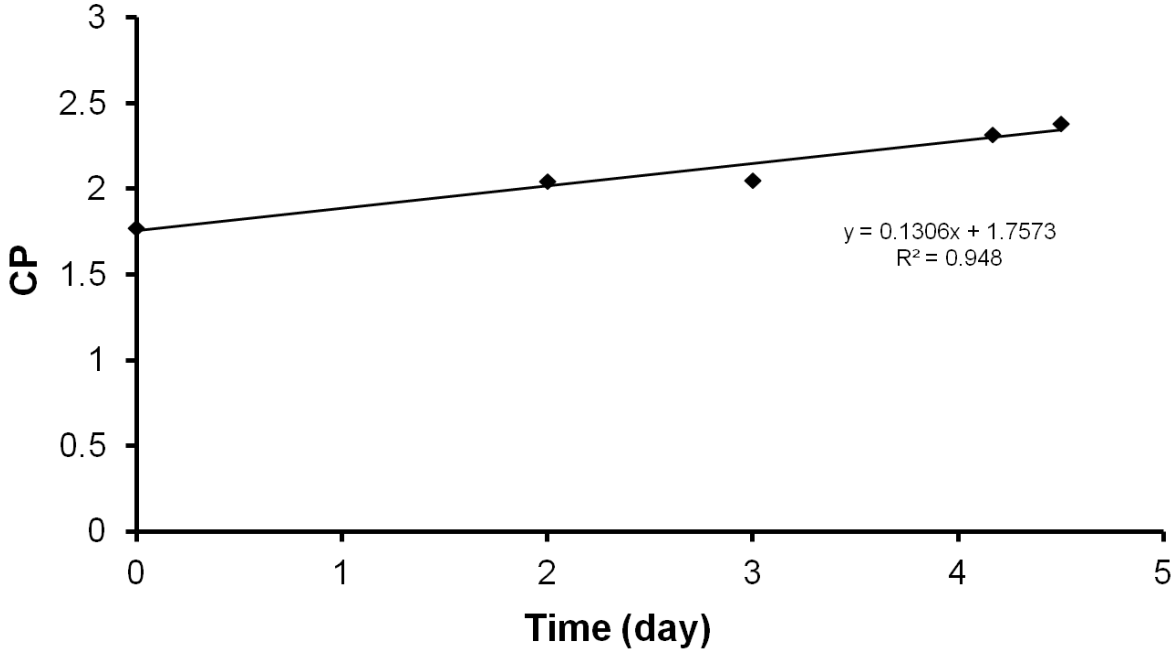

3
2.5
2
1.5
1
0.5
0
CP
y = 0.1306x + 1.7573
R² = 0.948
0
1
2
3
4
5
Time (day)

FIG. 23

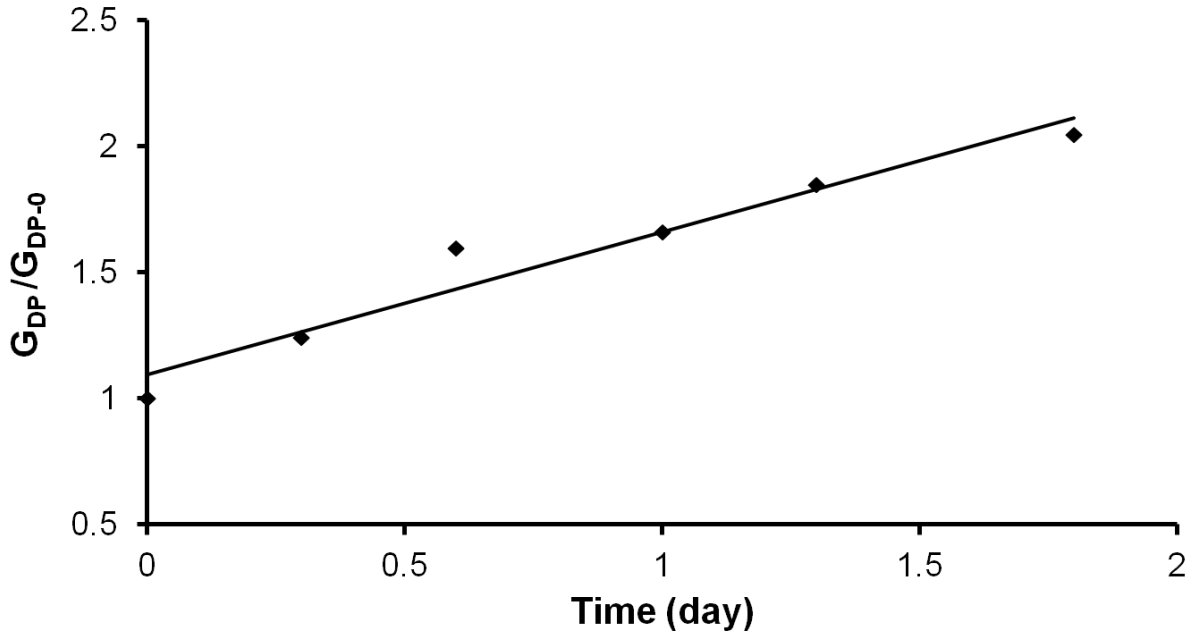


FIG. 24

(A)

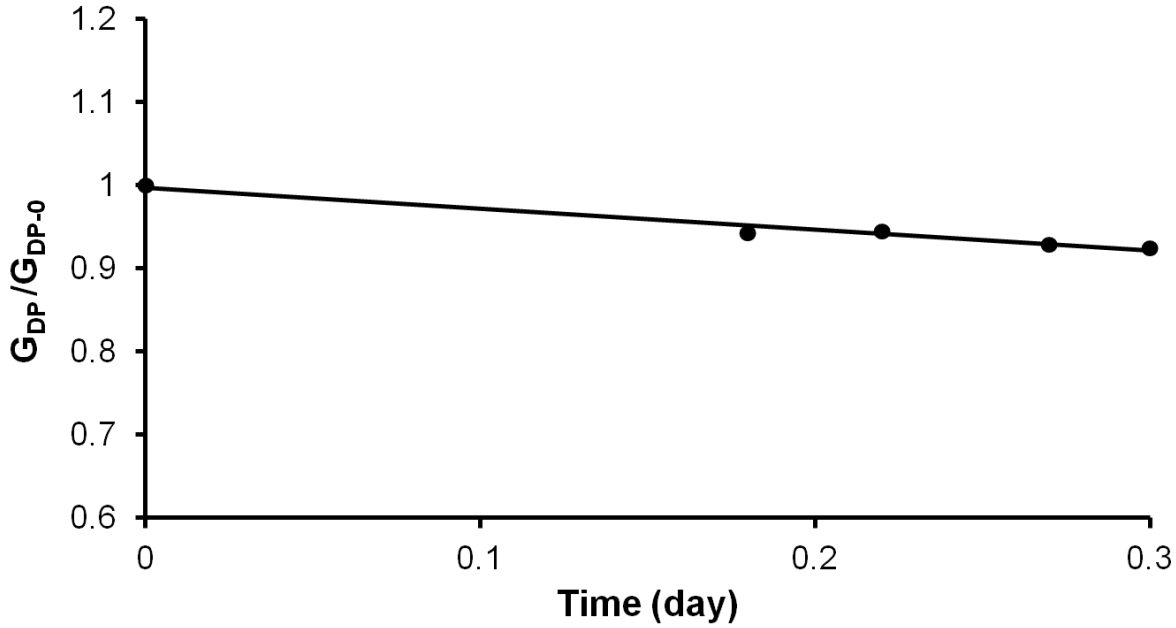


FIG. 24 (Cont.)

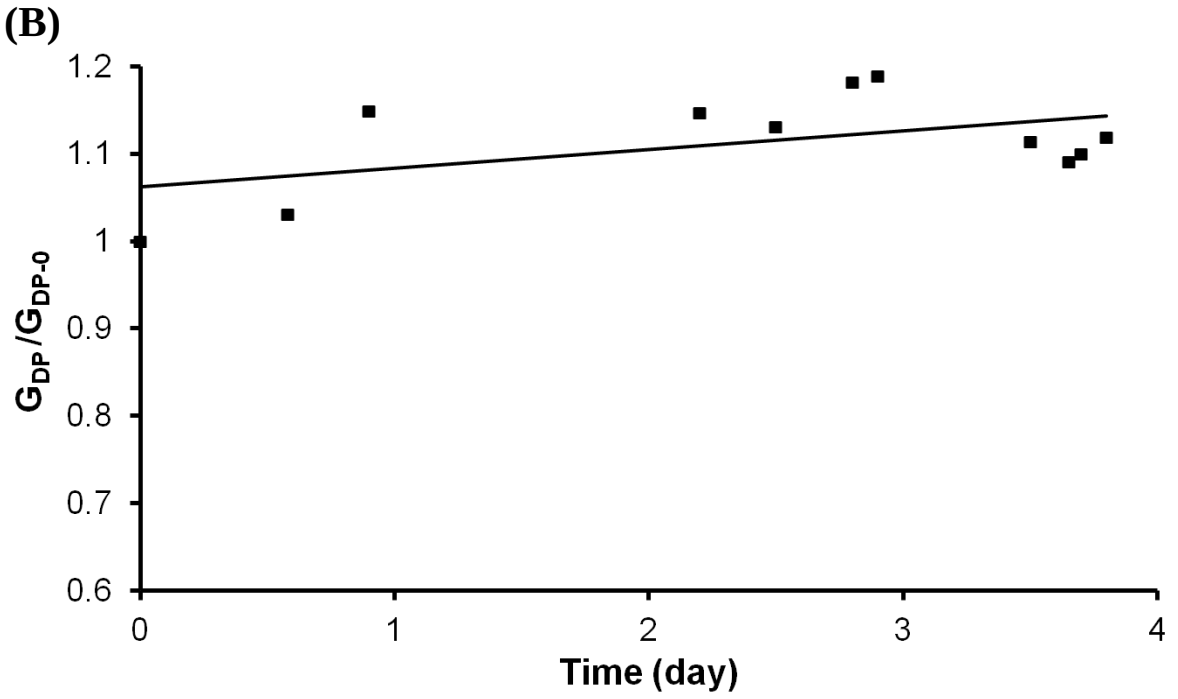


FIG. 25

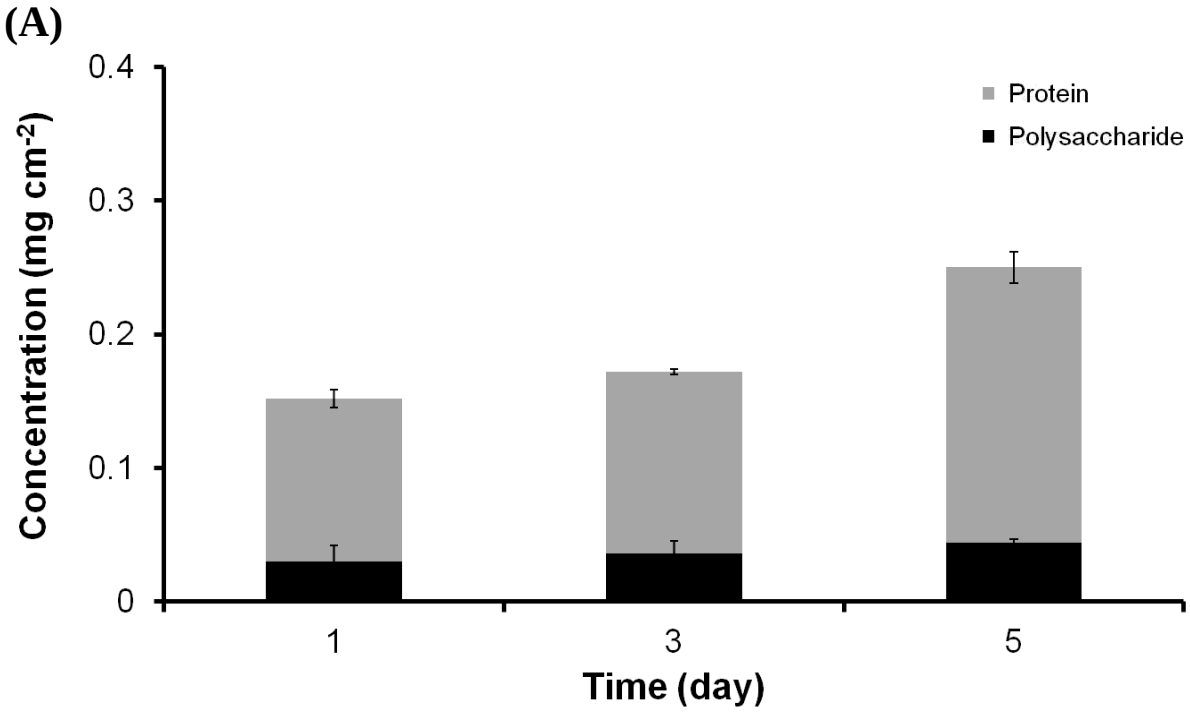
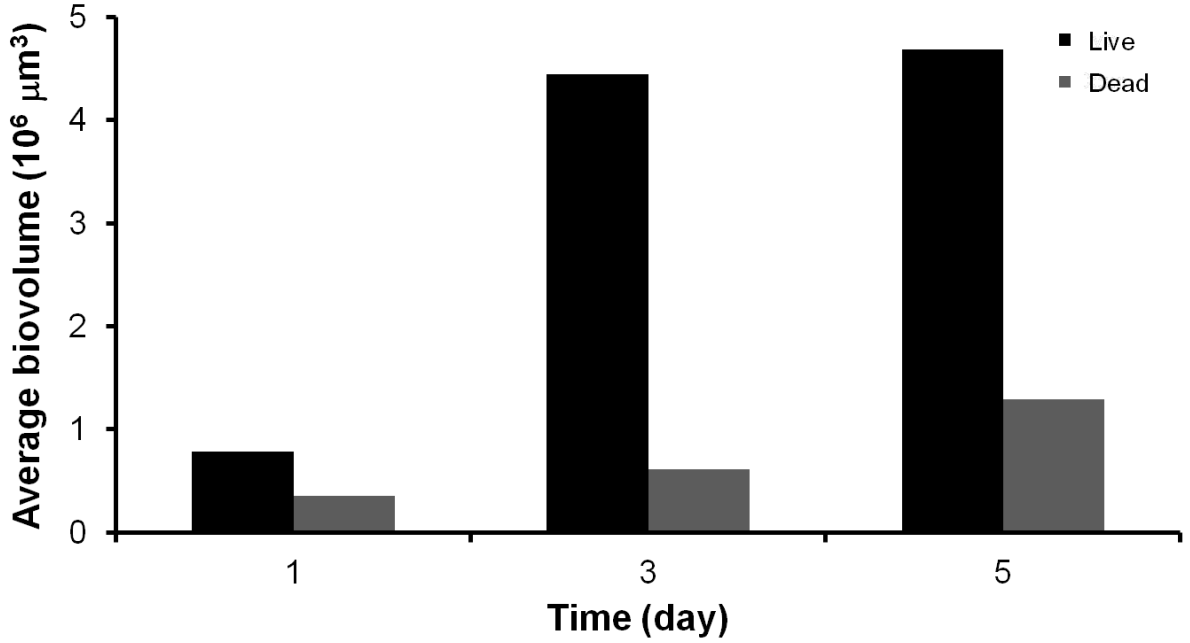


FIG. 25 (Cont.)

(B)



(C)

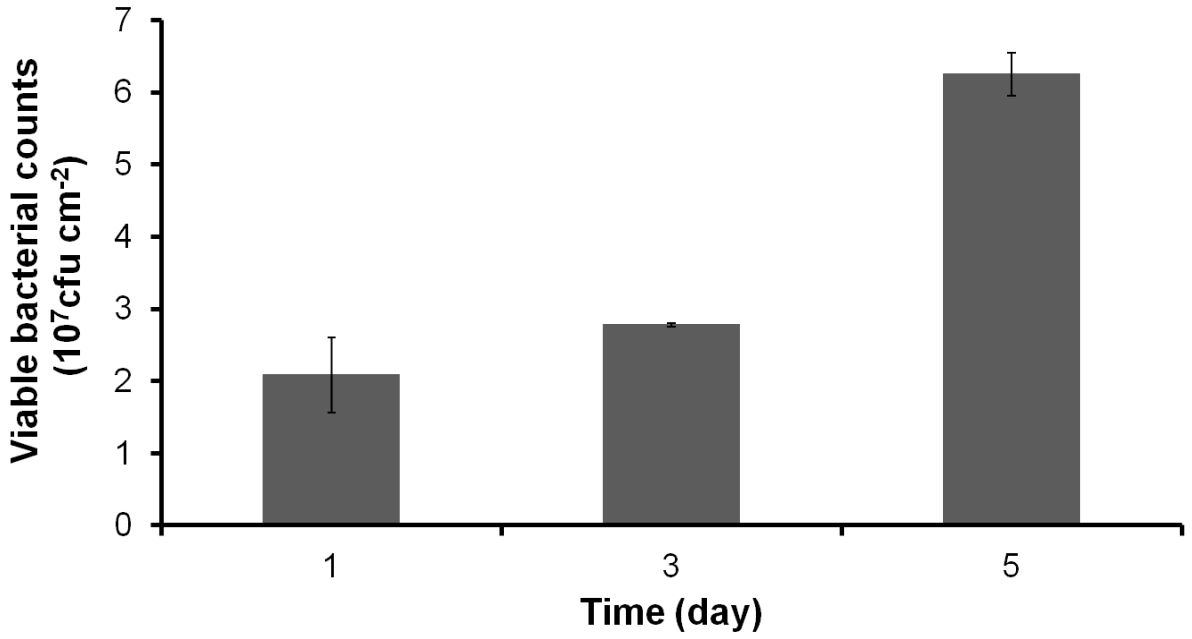


FIG. 26

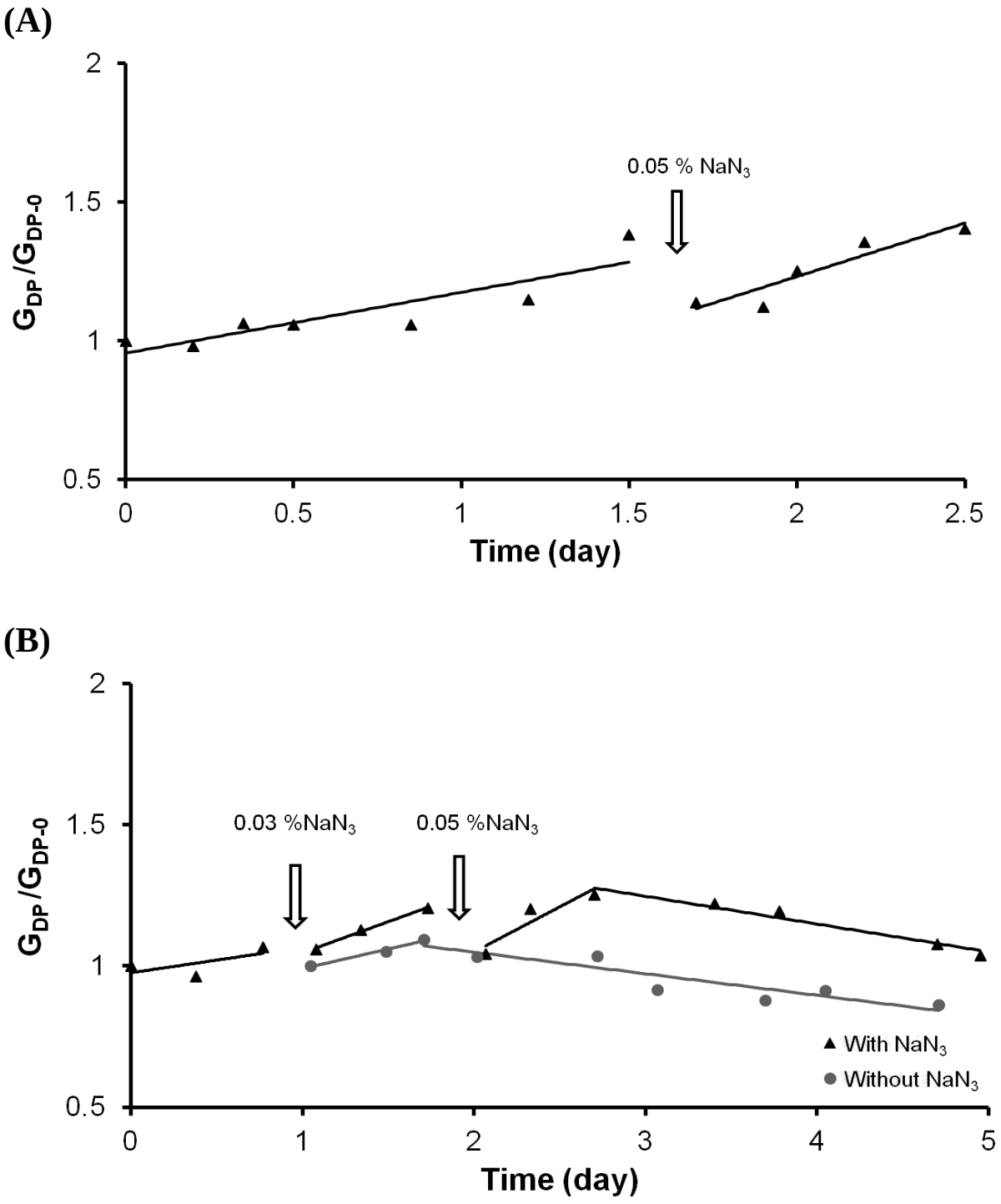
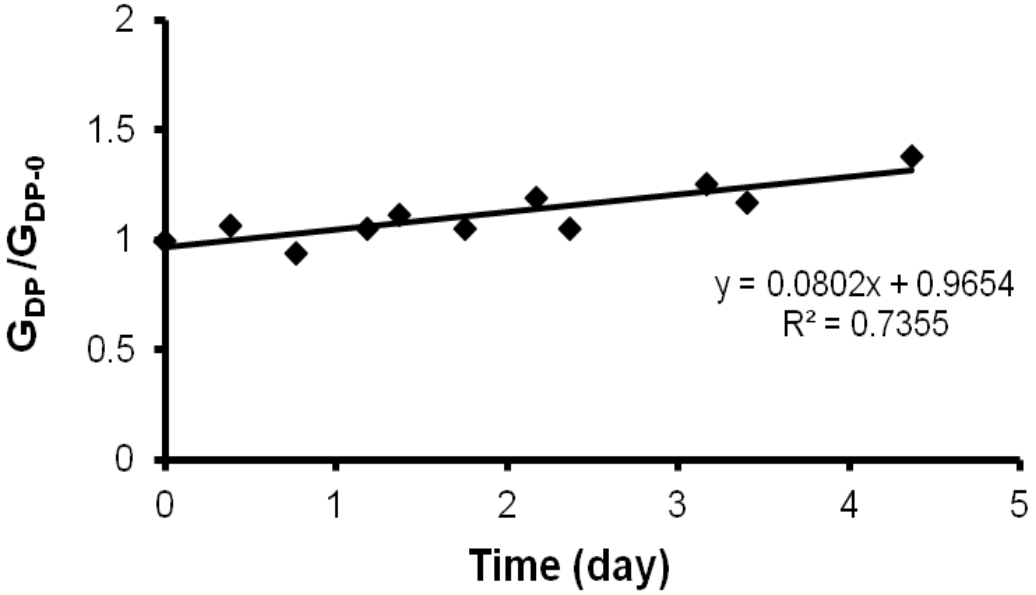

(A)
2
1.5
1
0.5
G_{DP}/G_{DP-0}
0.05 % NaN_3
0
0.5
1
1.5
2
2.5
Time (day)
(B)
2
1.5
1
0.5
G_{DP}/G_{DP-0}
0.03 %NaN_3
0.05 %NaN_3
With NaN_3
Without NaN_3
0
1
2
3
4
5
Time (day)

FIG. 27

(A)


2
1.5
1
0.5
0
0
1
2
3
4
5
G_{DP}/G_{DP-0}
Time (day)
y = 0.0802x + 0.9654
R² = 0.7355

(B)

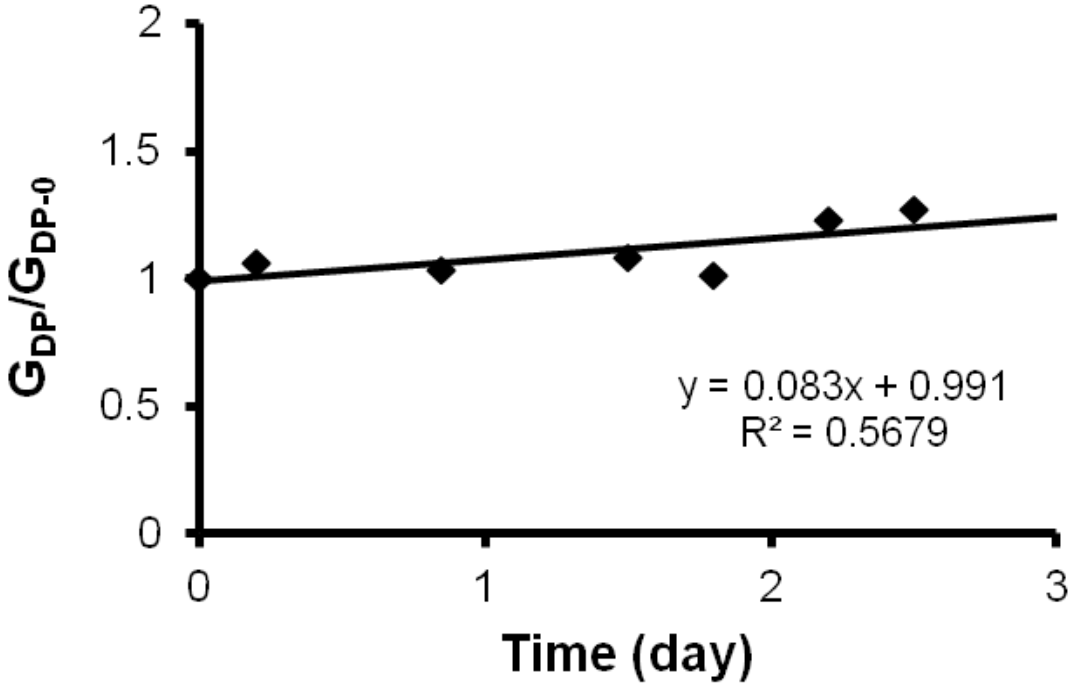
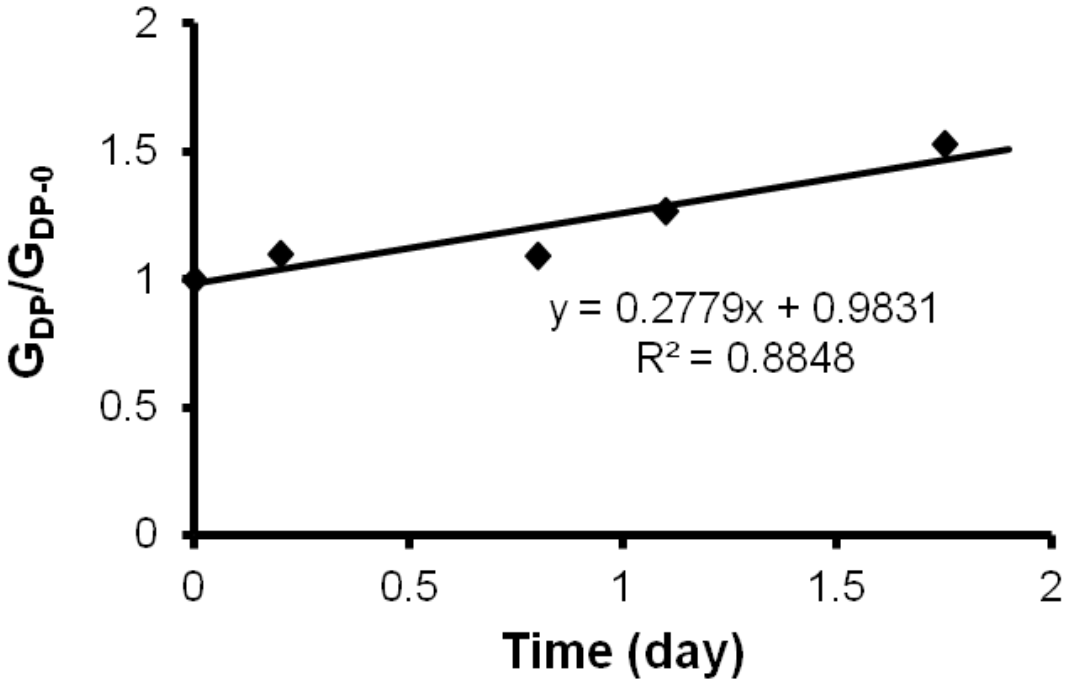

2
1.5
1
0.5
0
0
1
2
3
G_{DP}/G_{DP-0}
Time (day)
y = 0.083x + 0.991
R² = 0.5679

FIG. 27 (Cont.)

(C)



(D)

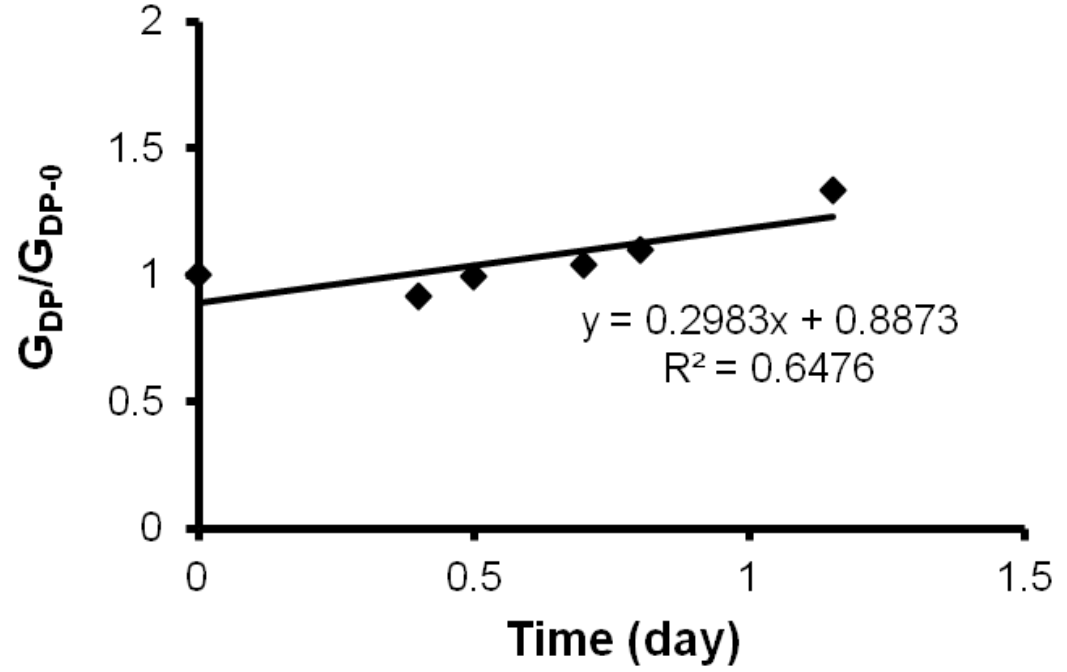


FIG. 27 (Cont.)

(E)

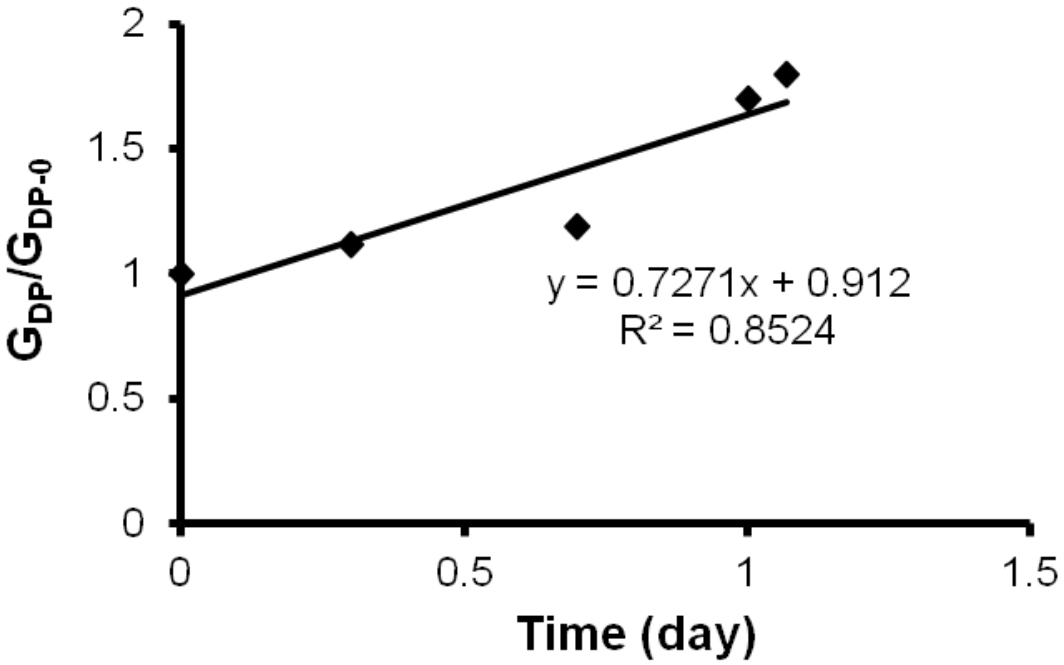


FIG. 28

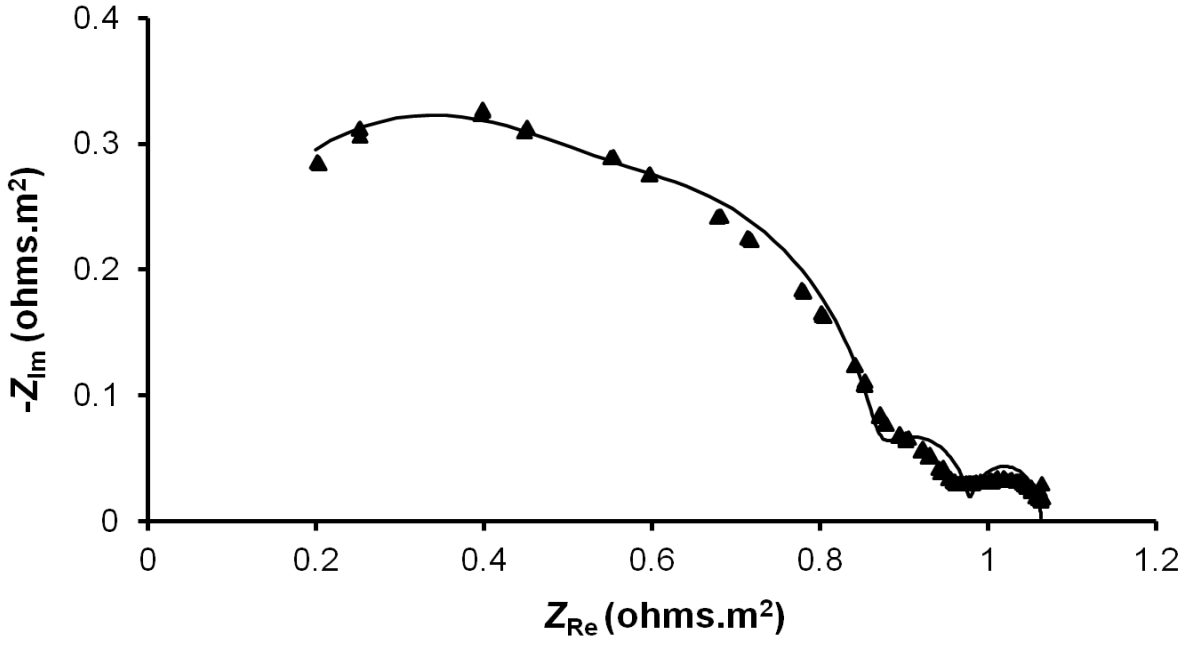
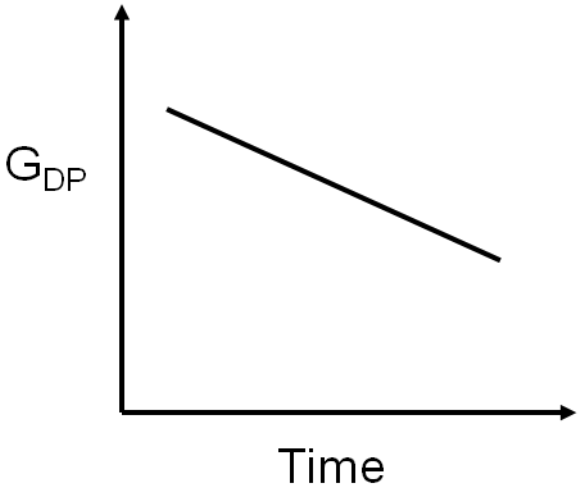
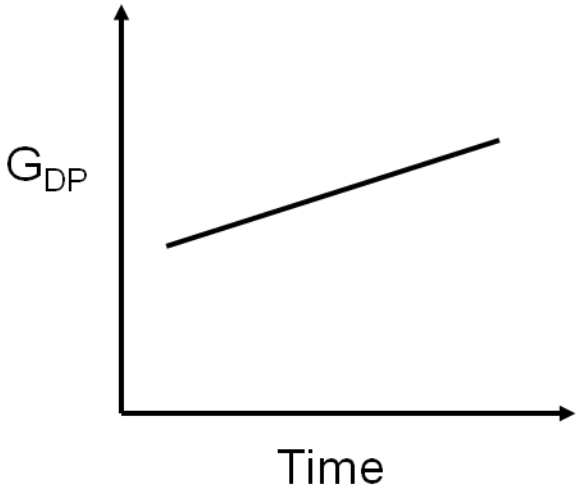


FIG. 29

(A)



(B)



(C)

