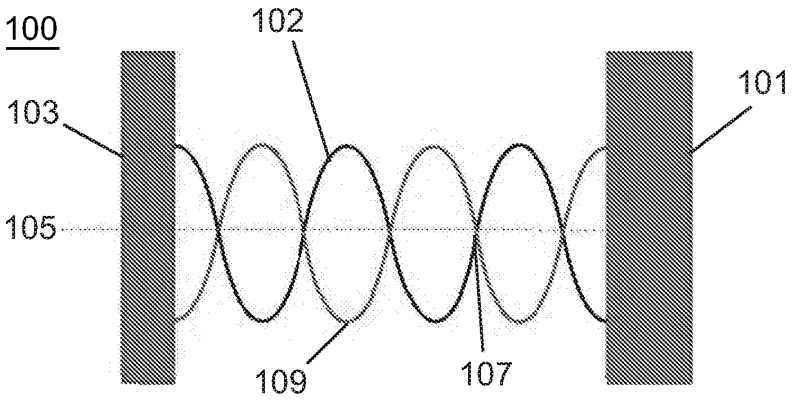

100
102
101
103
105
109
107

FIG. 1

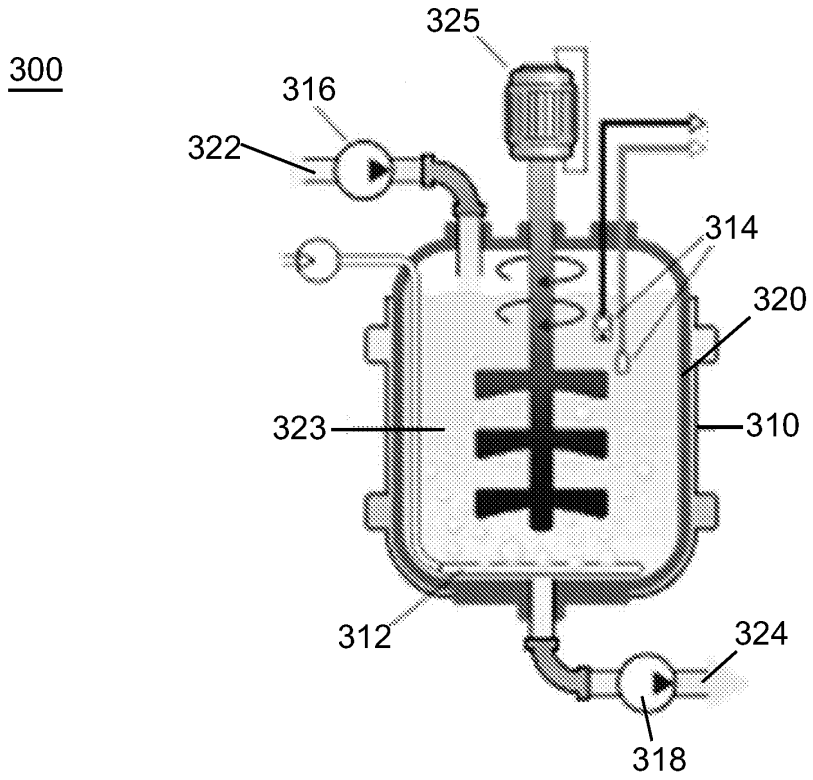

300
325
316
322
314
320
323
310
312
324
318

FIG. 3

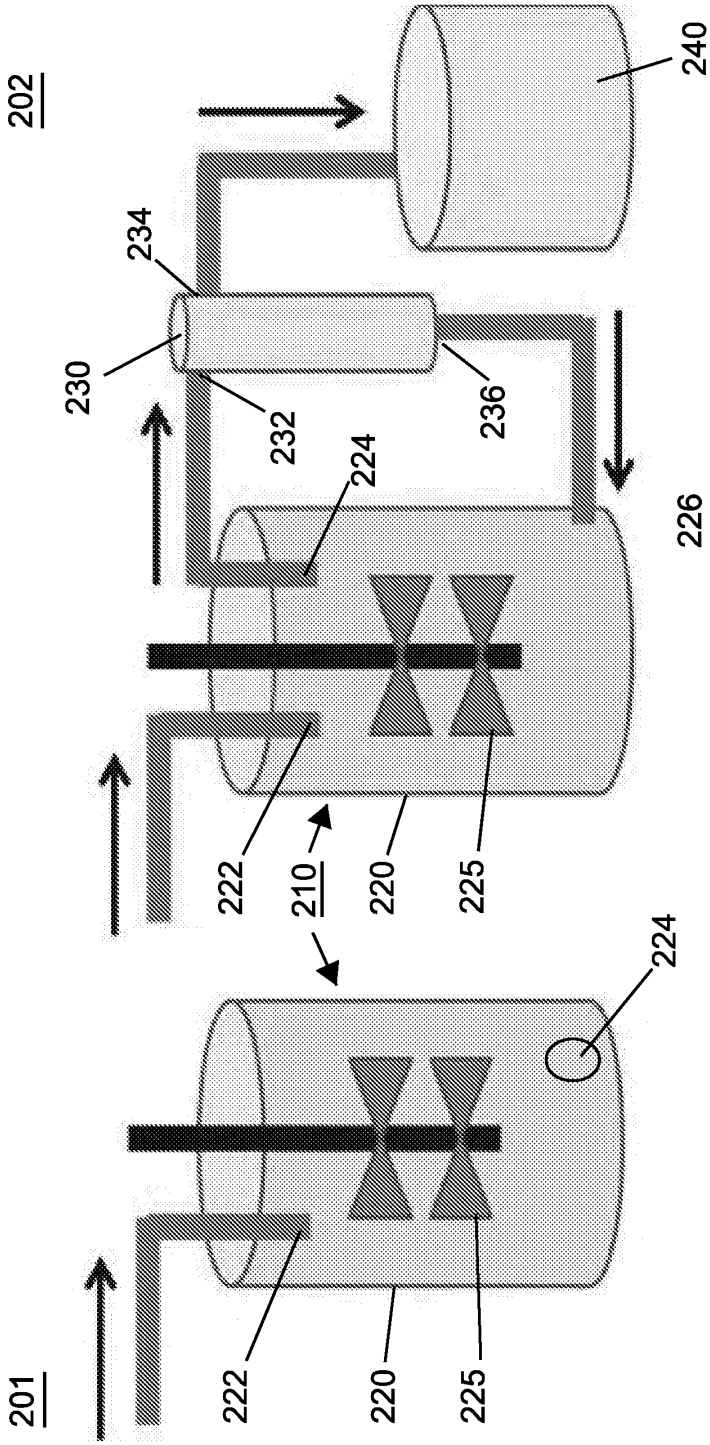

202
240
234
230
232
236
224
226
222
210
220
225
224
201
222
220
225

FIG. 2

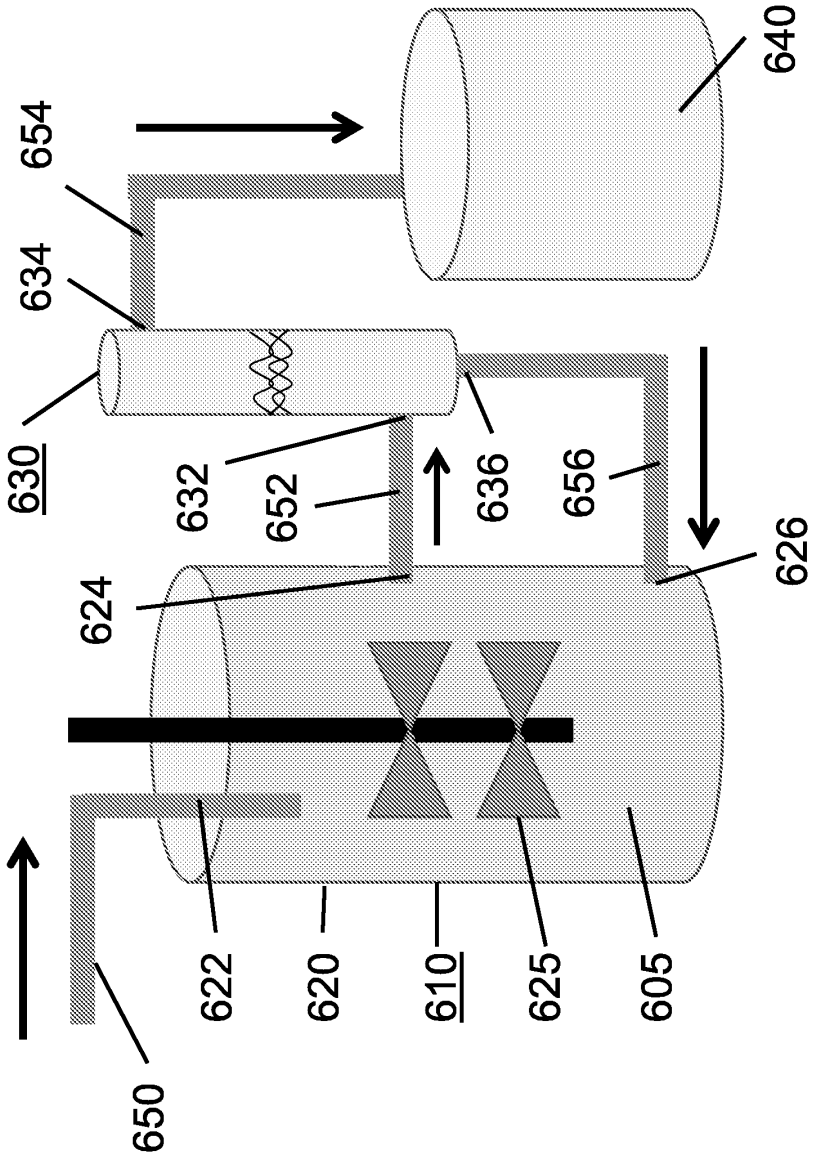


FIG. 4

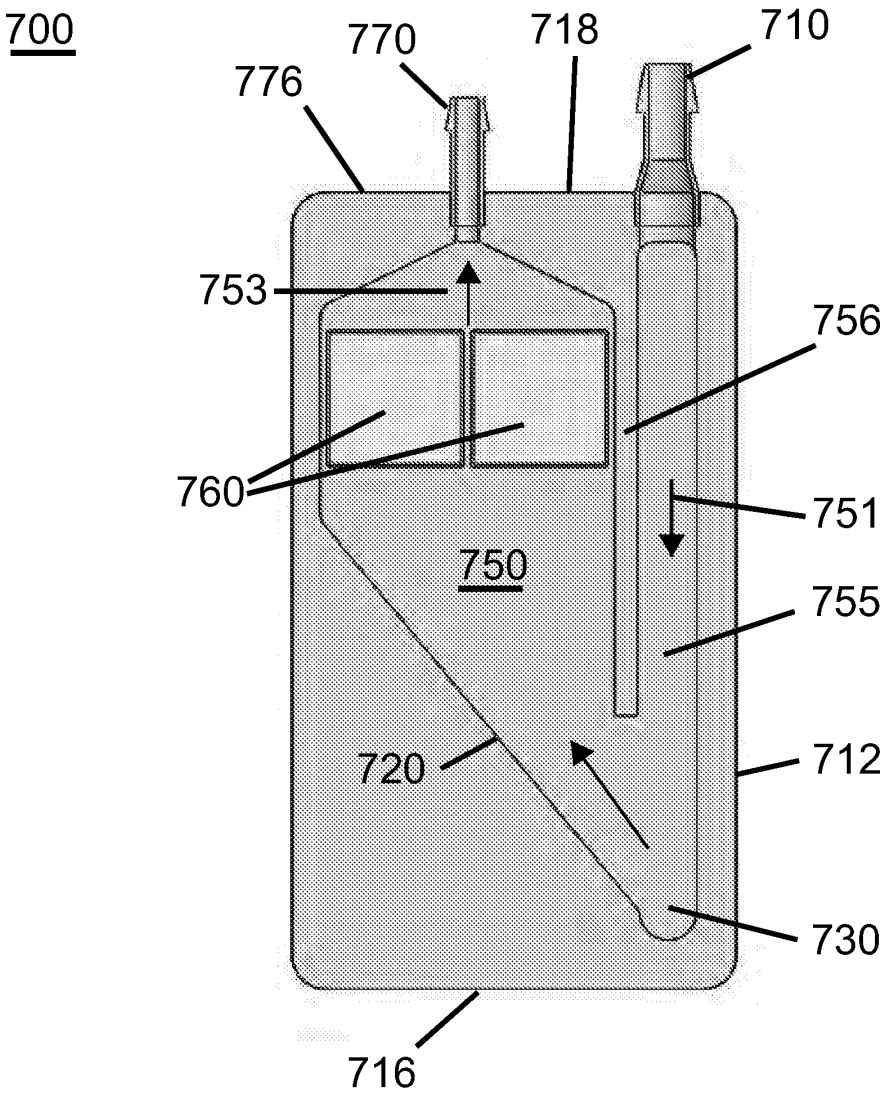


FIG. 5

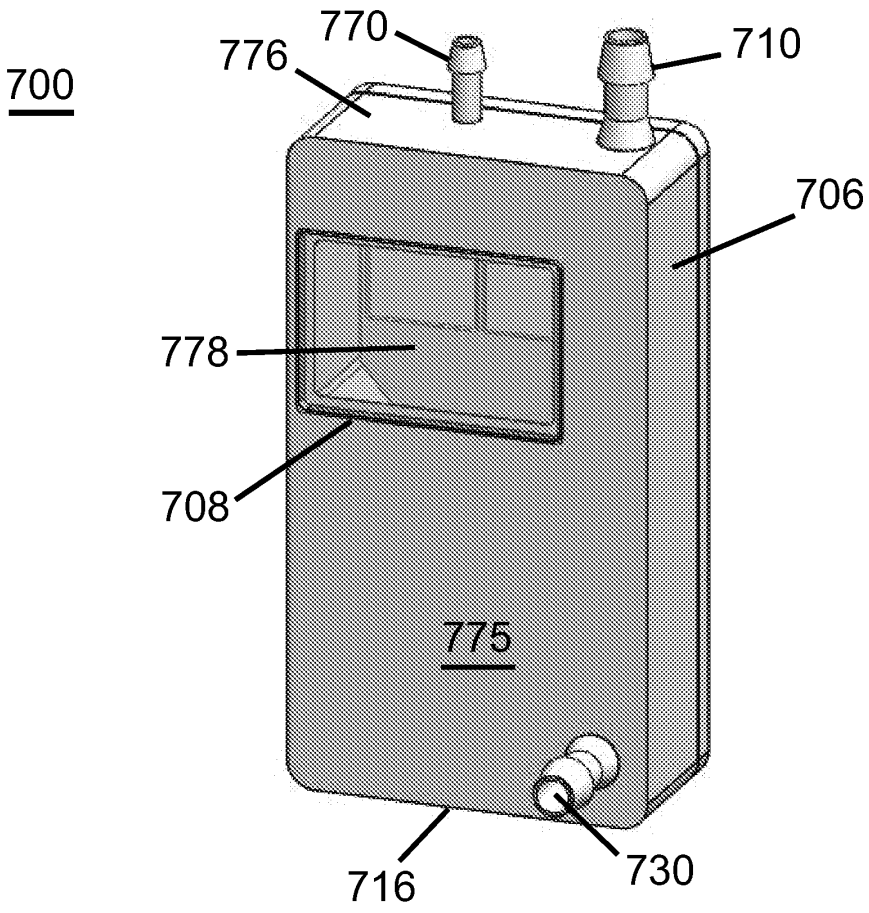


FIG. 6

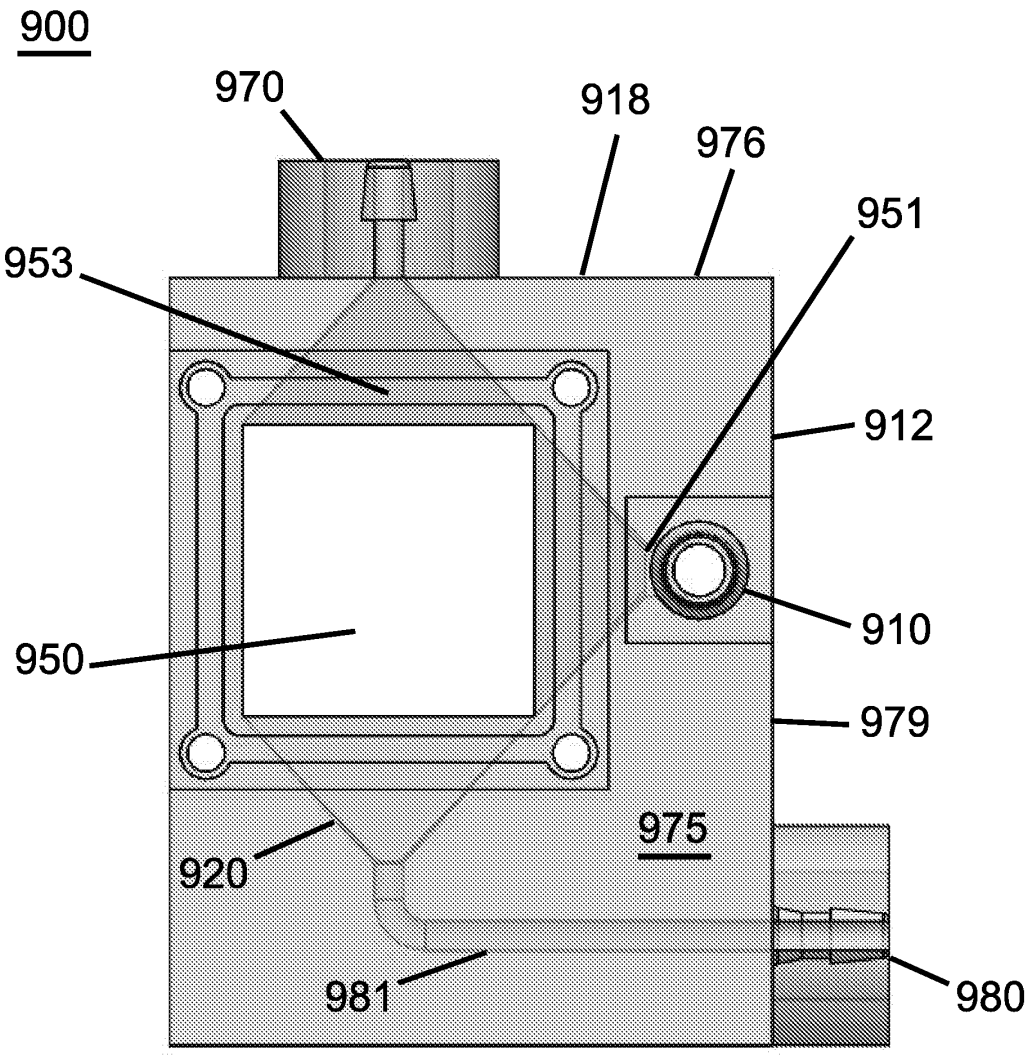


FIG. 7

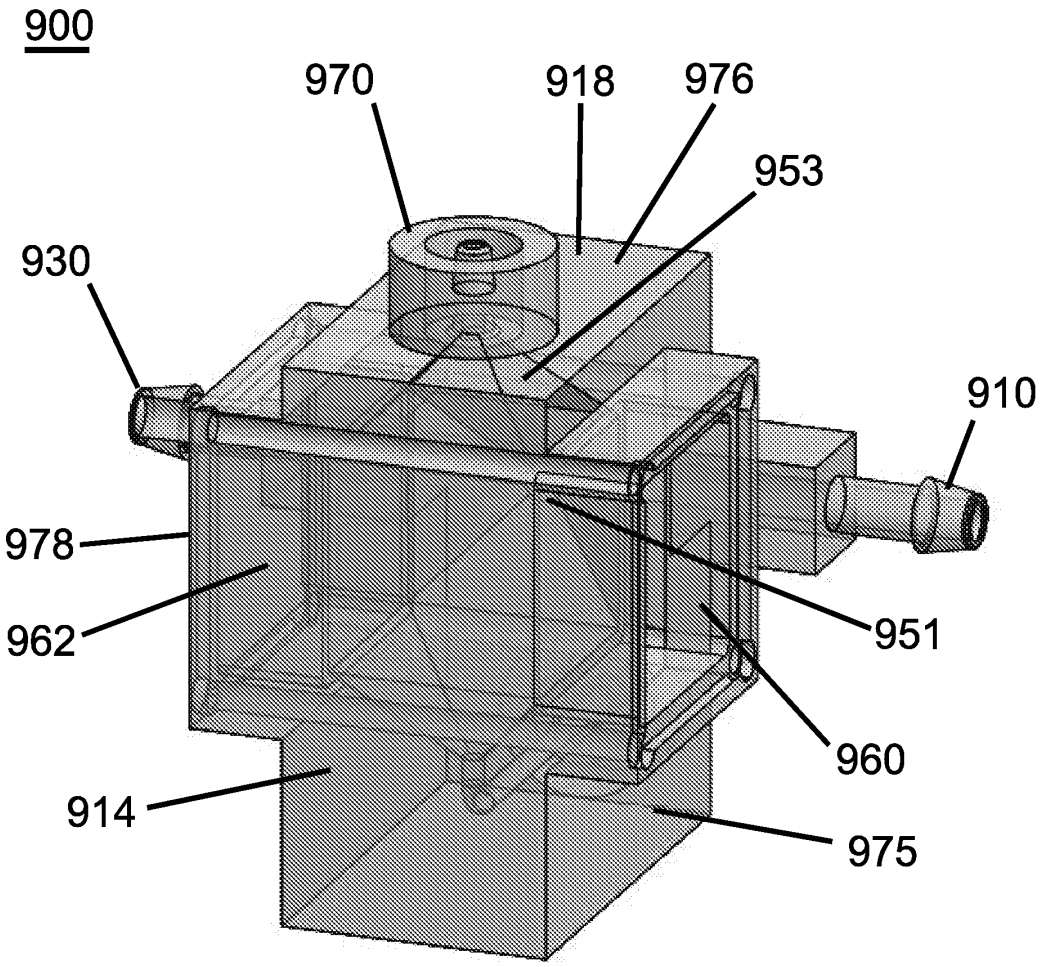


FIG. 8

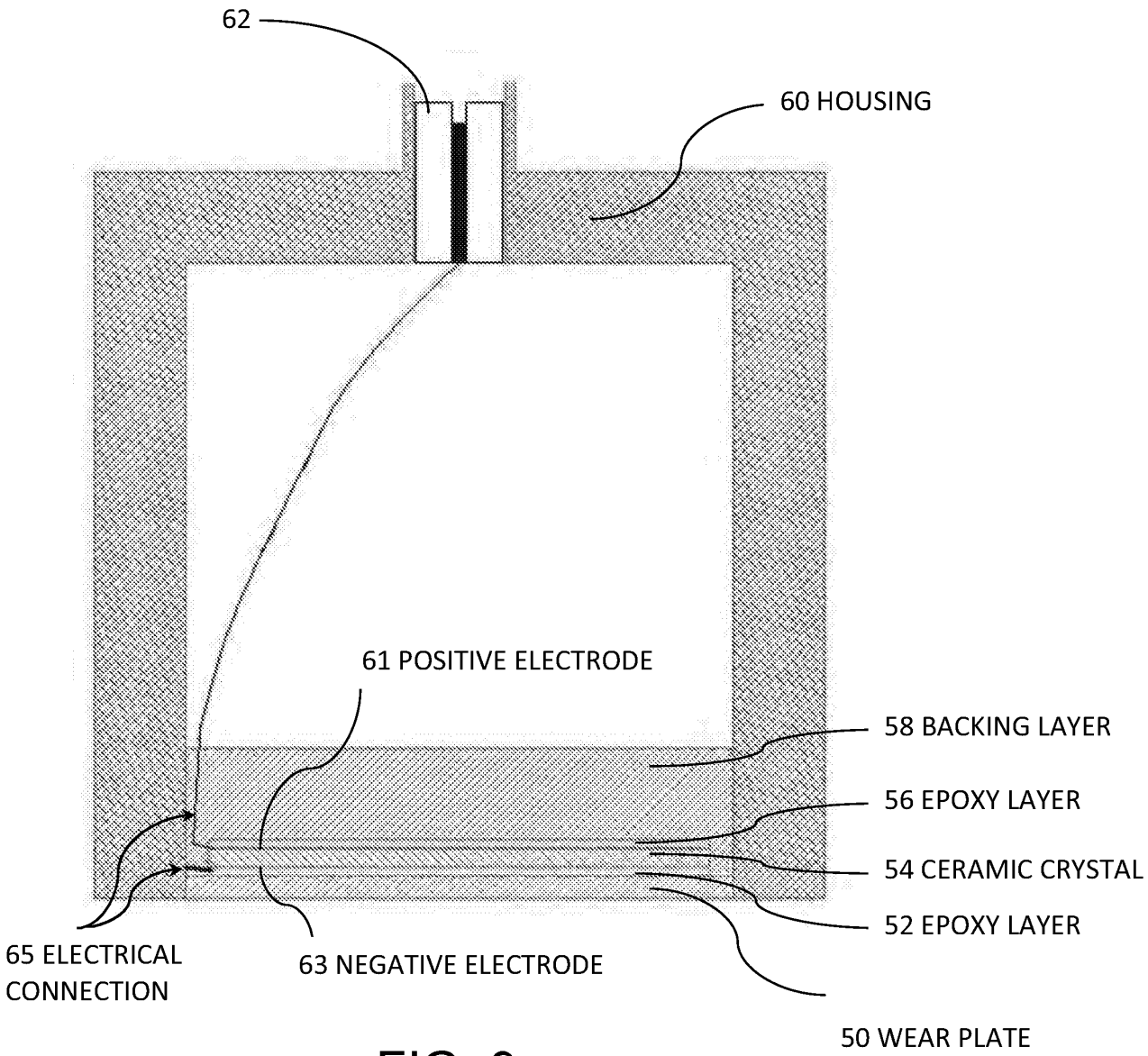

62
60 HOUSING
61 POSITIVE ELECTRODE
58 BACKING LAYER
56 EPOXY LAYER
54 CERAMIC CRYSTAL
52 EPOXY LAYER
65 ELECTRICAL CONNECTION
63 NEGATIVE ELECTRODE
50 WEAR PLATE

FIG. 9

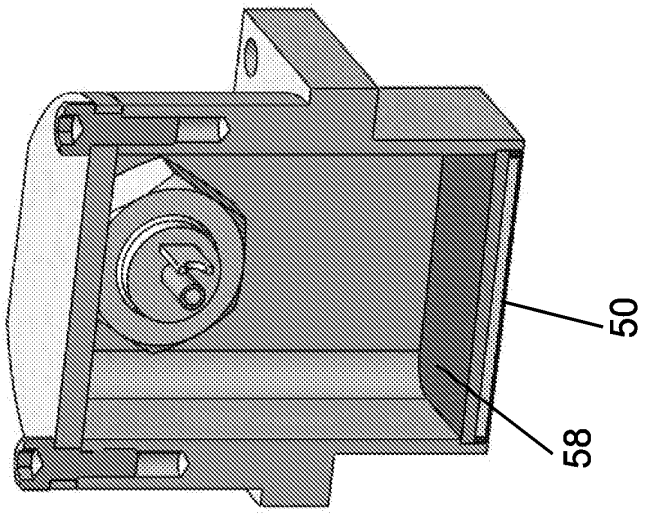


FIG. 11

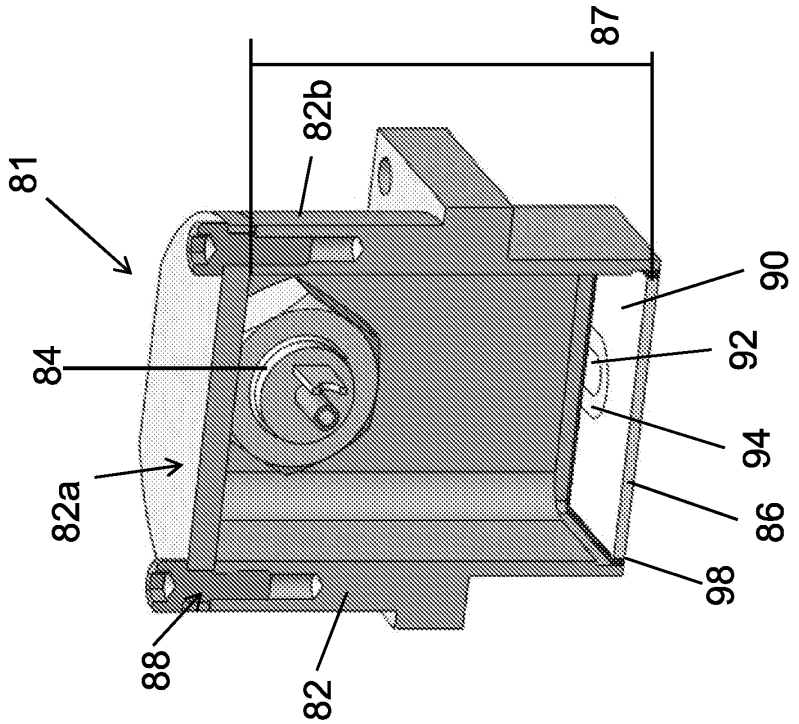


FIG. 10

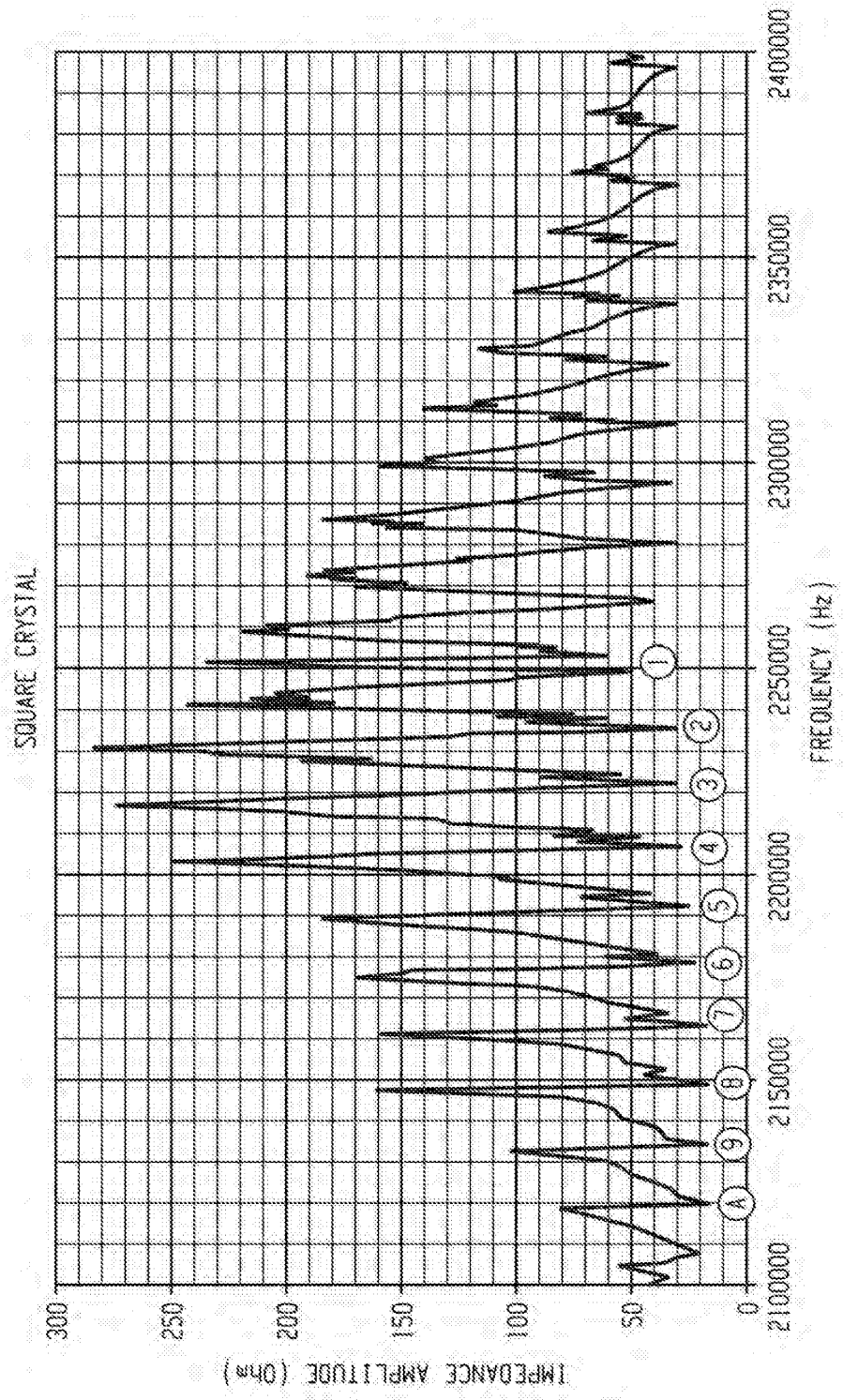

SQUARE CRYSTAL
IMPEDANCE AMPLITUDE (Ohm)
300
250
200
150
100
50
0
2100000
2150000
2200000
2250000
2300000
2350000
2400000
FREQUENCY (Hz)
1
2
3
4
5
6
7
8
9
A

FIG. 12

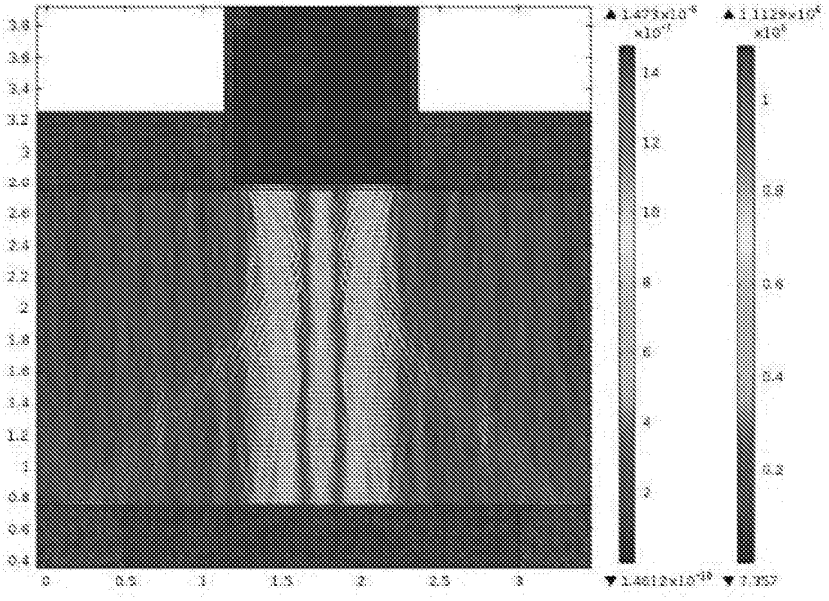


FIG. 14

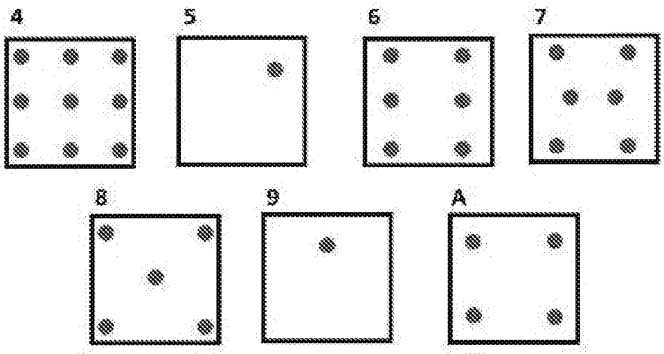


FIG. 13

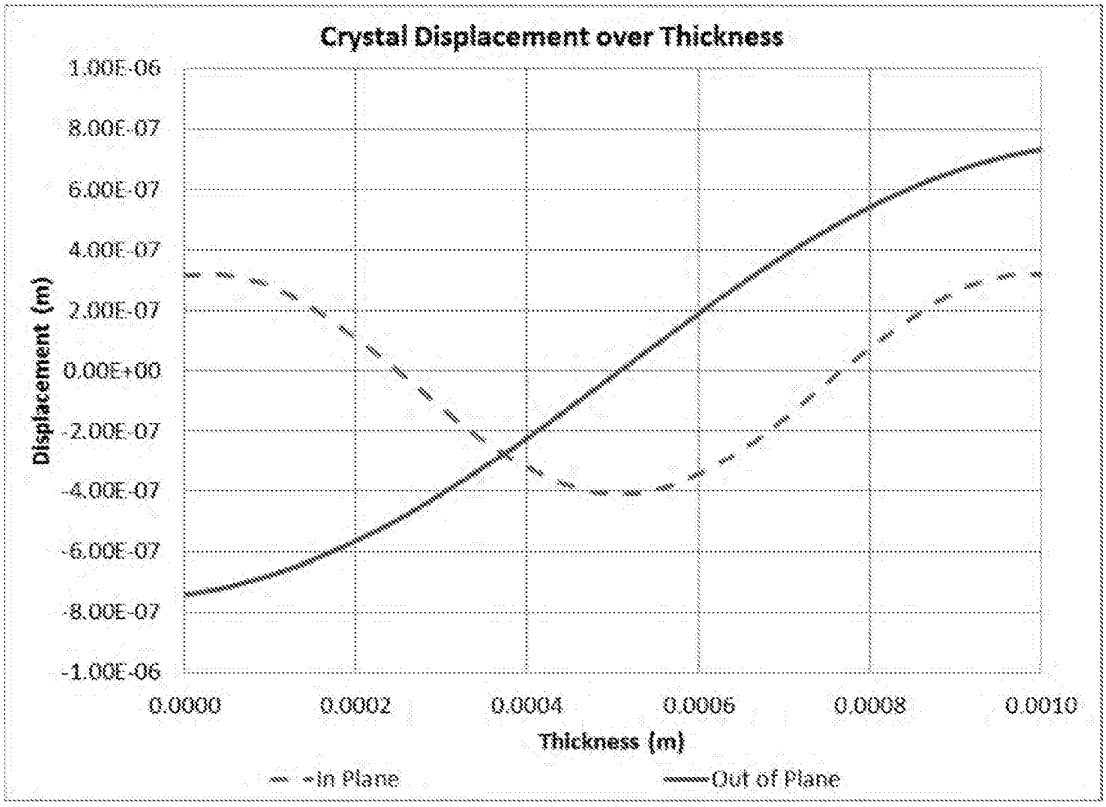

Crystal Displacement over Thickness
1.00E-06
8.00E-07
6.00E-07
4.00E-07
2.00E-07
0.00E+00
-2.00E-07
-4.00E-07
-6.00E-07
-8.00E-07
-1.00E-06
Displacement (m)
0.0000
0.0002
0.0004
0.0006
0.0008
0.0010
Thickness (m)
In Plane
Out of Plane

FIG. 15

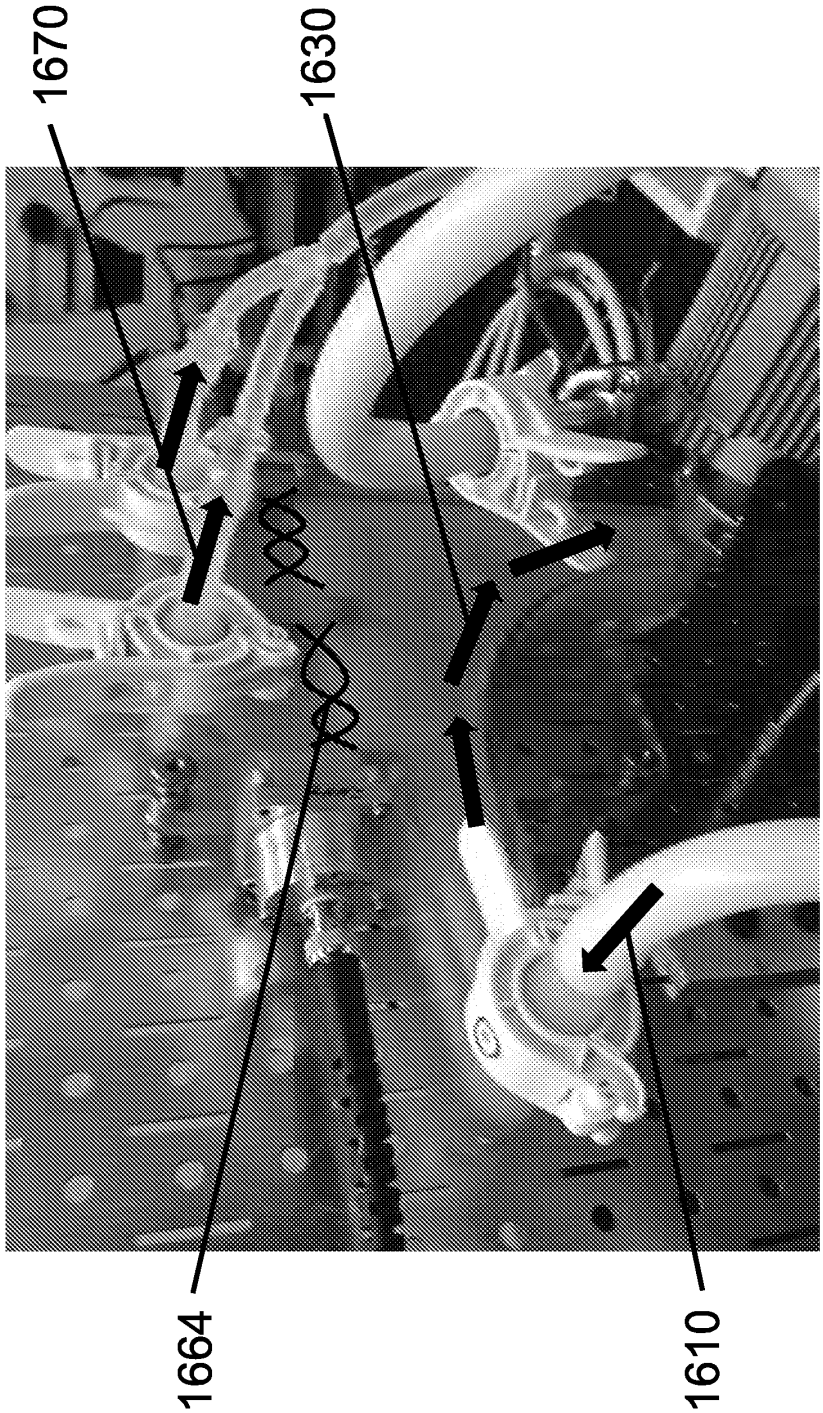


FIG. 16

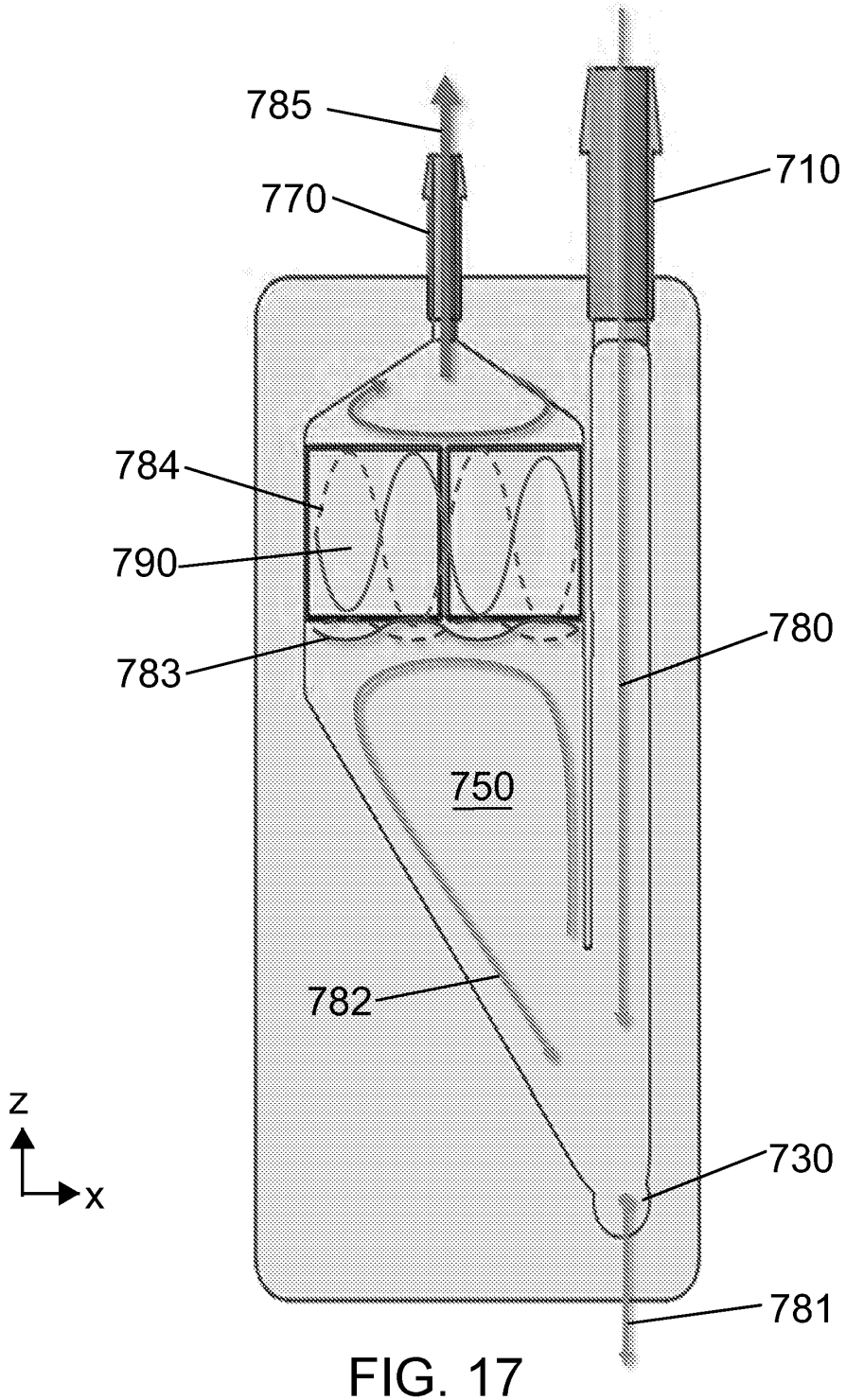


FIG. 17

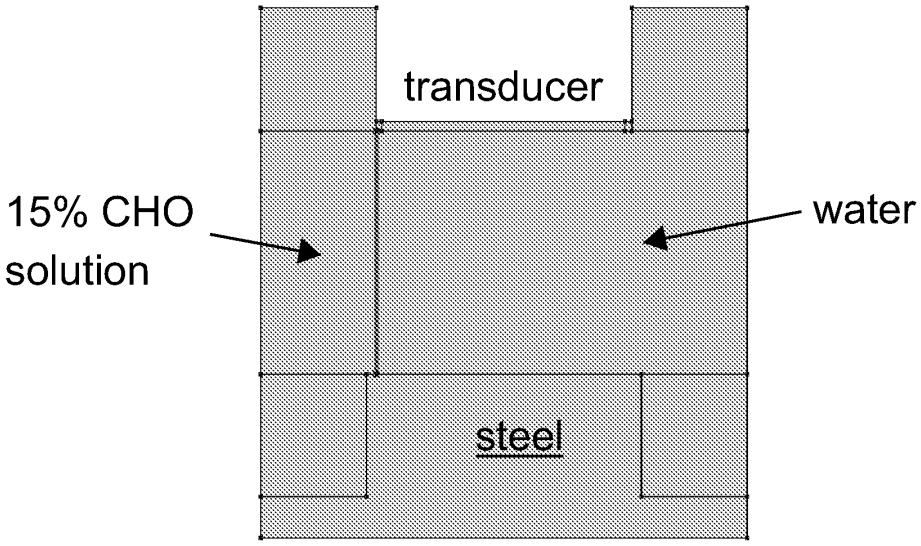


FIG. 18

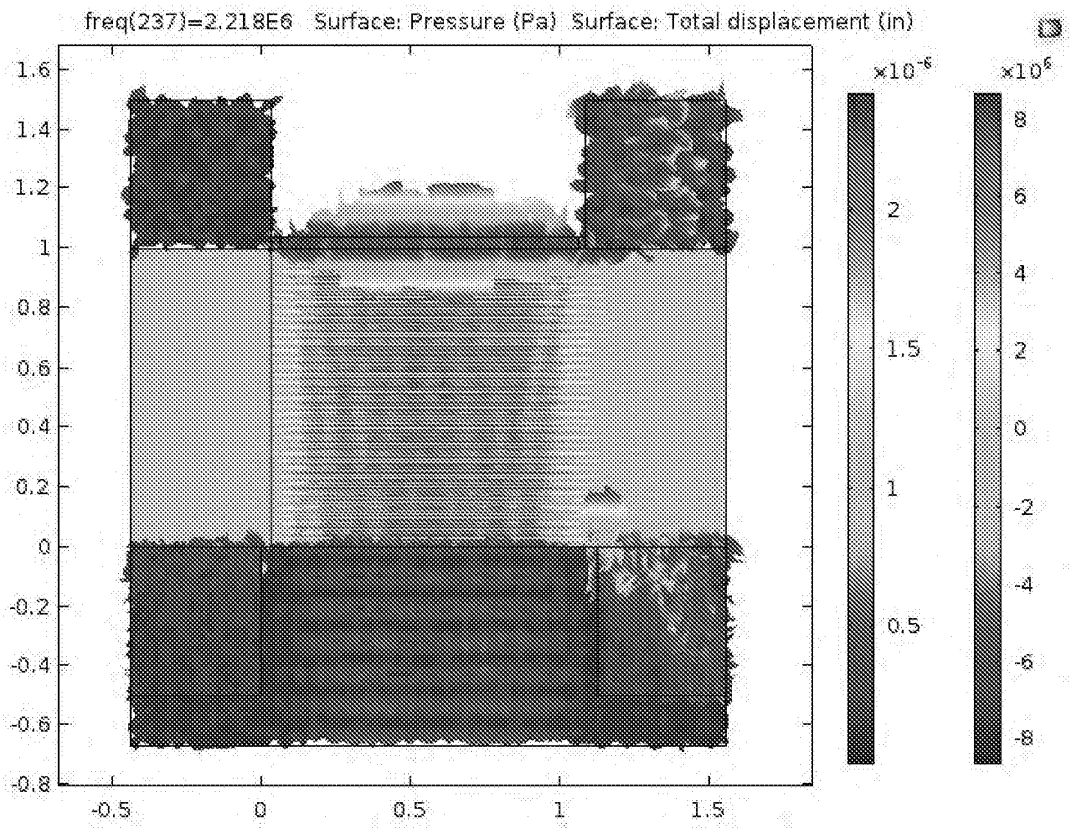

freq(237)=2.218E6 Surface: Pressure (Pa) Surface: Total displacement (in)
×10⁻⁶
×10⁶
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-0.5
0
0.5
1
1.5
2
1.5
1
0.5
8
6
4
2
0
-2
-4
-6
-8

FIG. 19A

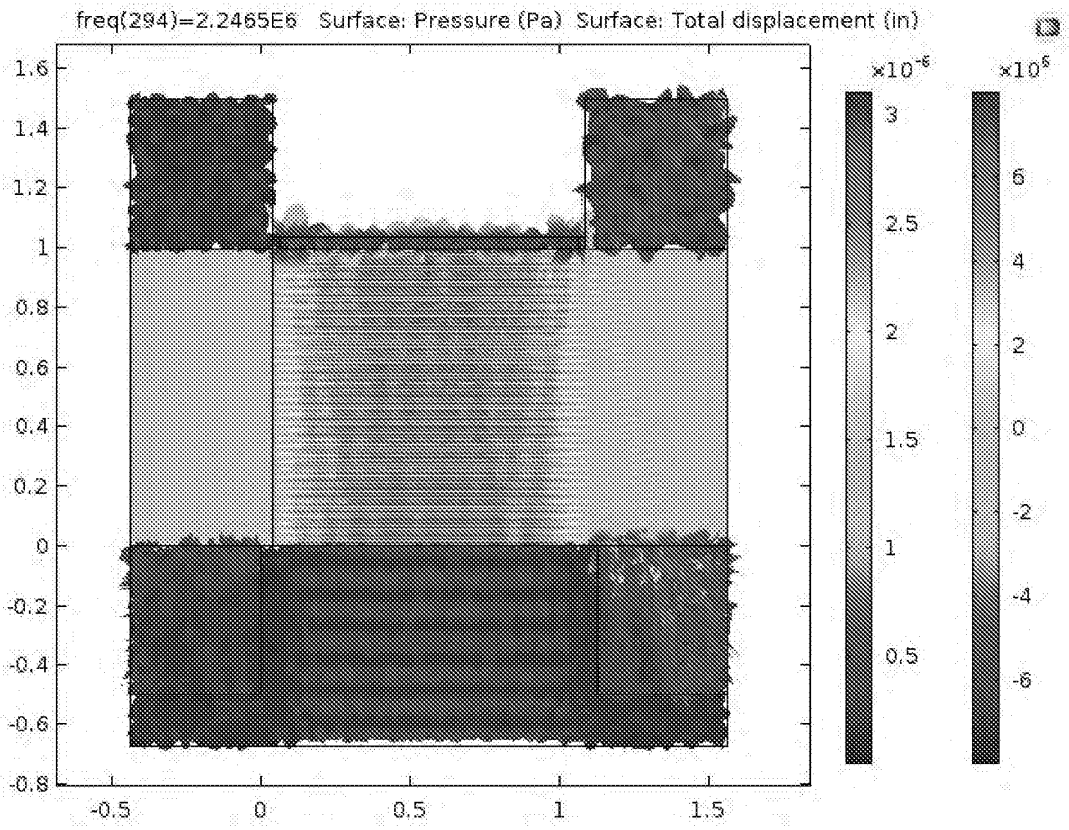

freq(294)=2.2465E6 Surface: Pressure (Pa) Surface: Total displacement (in)
×10⁻⁶
×10⁵
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-0.5
0
0.5
1
1.5
3
2.5
2
1.5
1
0.5
6
4
2
0
-2
-4
-6

FIG. 19B

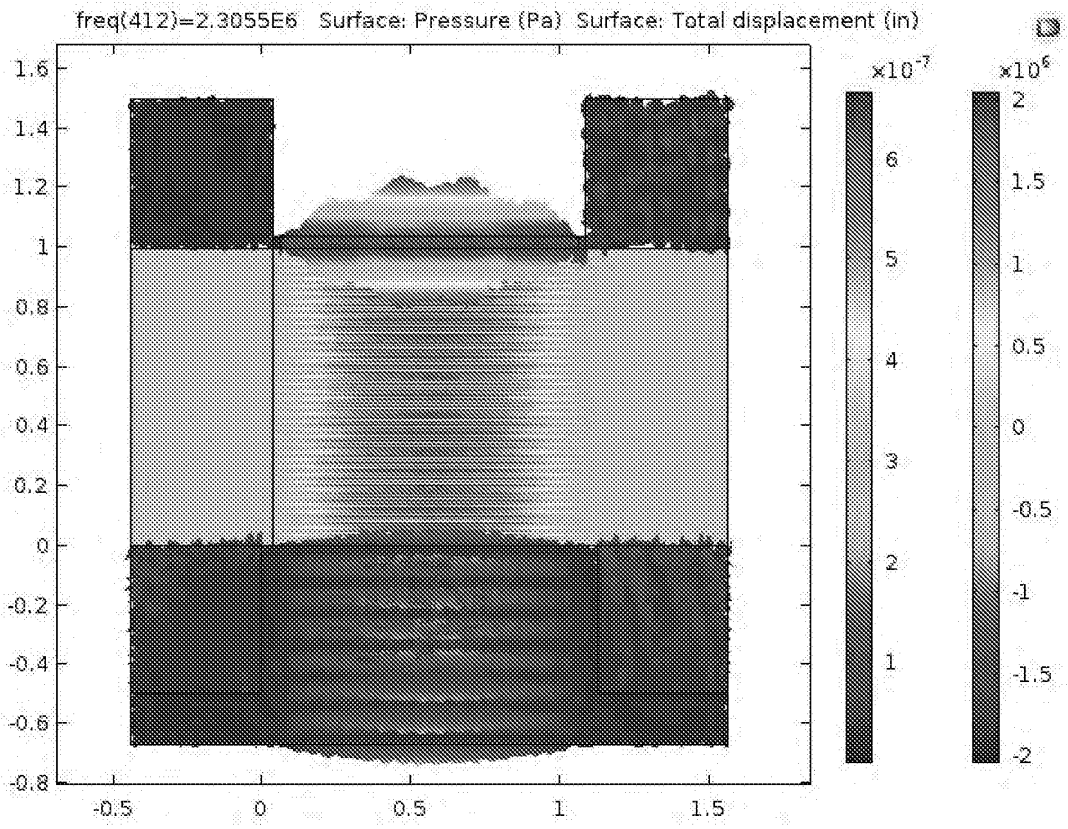

freq(412)=2.3055E6 Surface: Pressure (Pa) Surface: Total displacement (in)
×10^-7
×10^6
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-0.5
0
0.5
1
1.5
6
5
4
3
2
1
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2

FIG. 19C

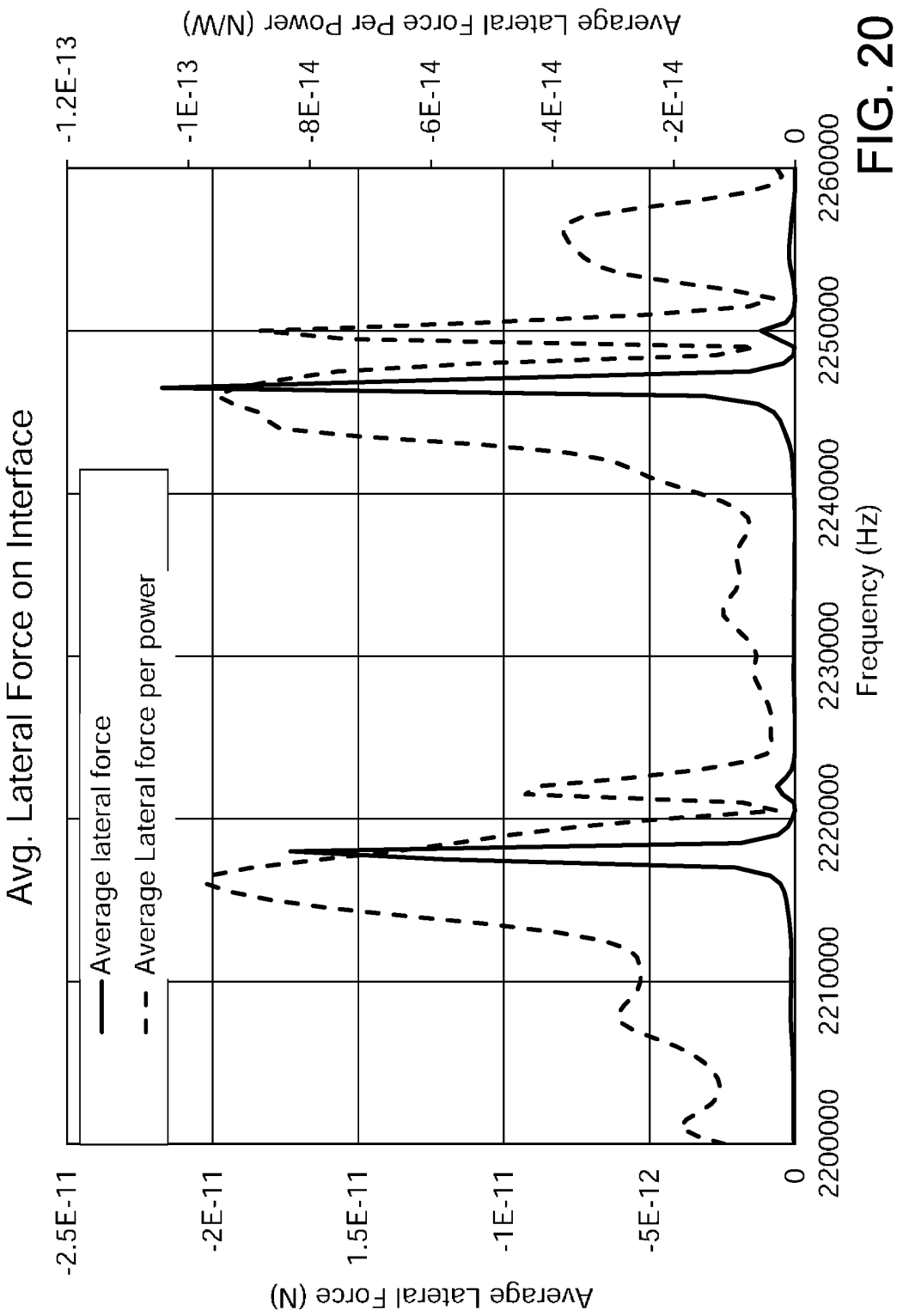

Avg. Lateral Force on Interface
Average lateral force
Average Lateral force per power
Average Lateral Force (N)
-2.5E-11
-2E-11
1.5E-11
-1E-11
-5E-12
0
Average Lateral Force Per Power (N/W)
-1.2E-13
-1E-13
-8E-14
-6E-14
-4E-14
-2E-14
0
2200000
2210000
2220000
2230000
2240000
2250000
2260000
Frequency (Hz)

FIG. 20

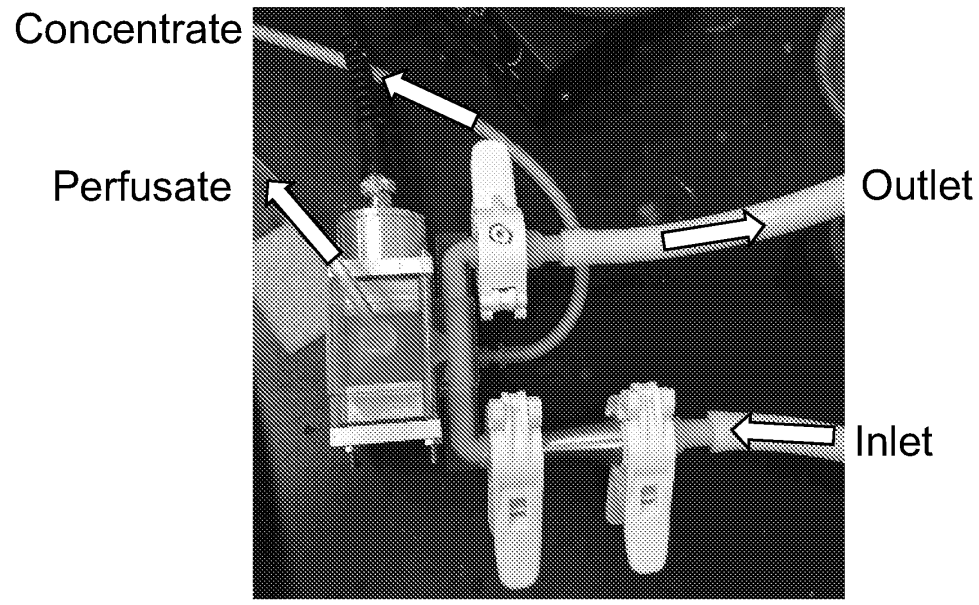

Concentrate
Perfusate
Outlet
Inlet

FIG. 21

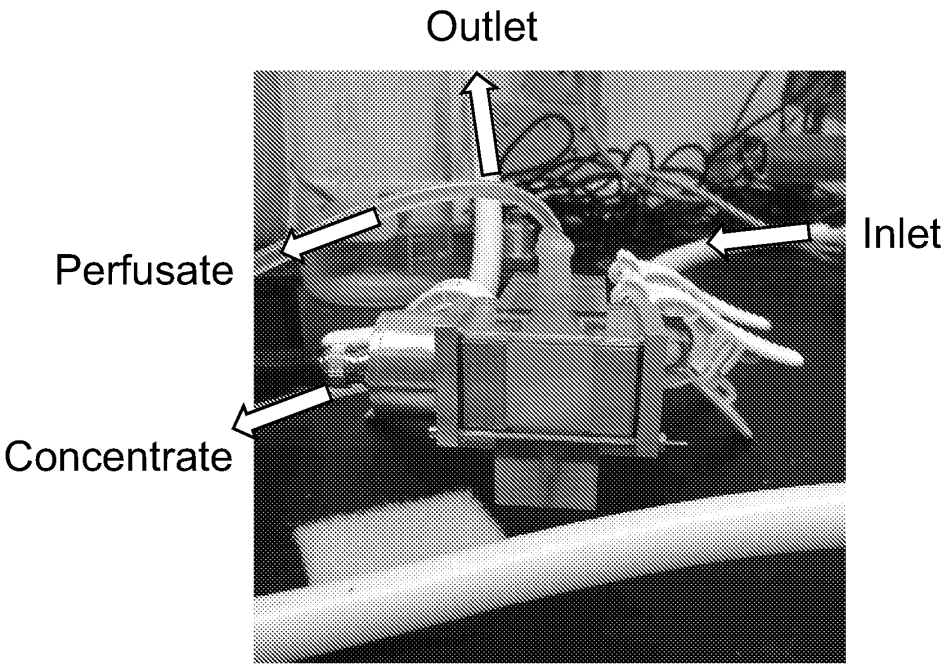

Outlet
Perfusate
Inlet
Concentrate

FIG. 22

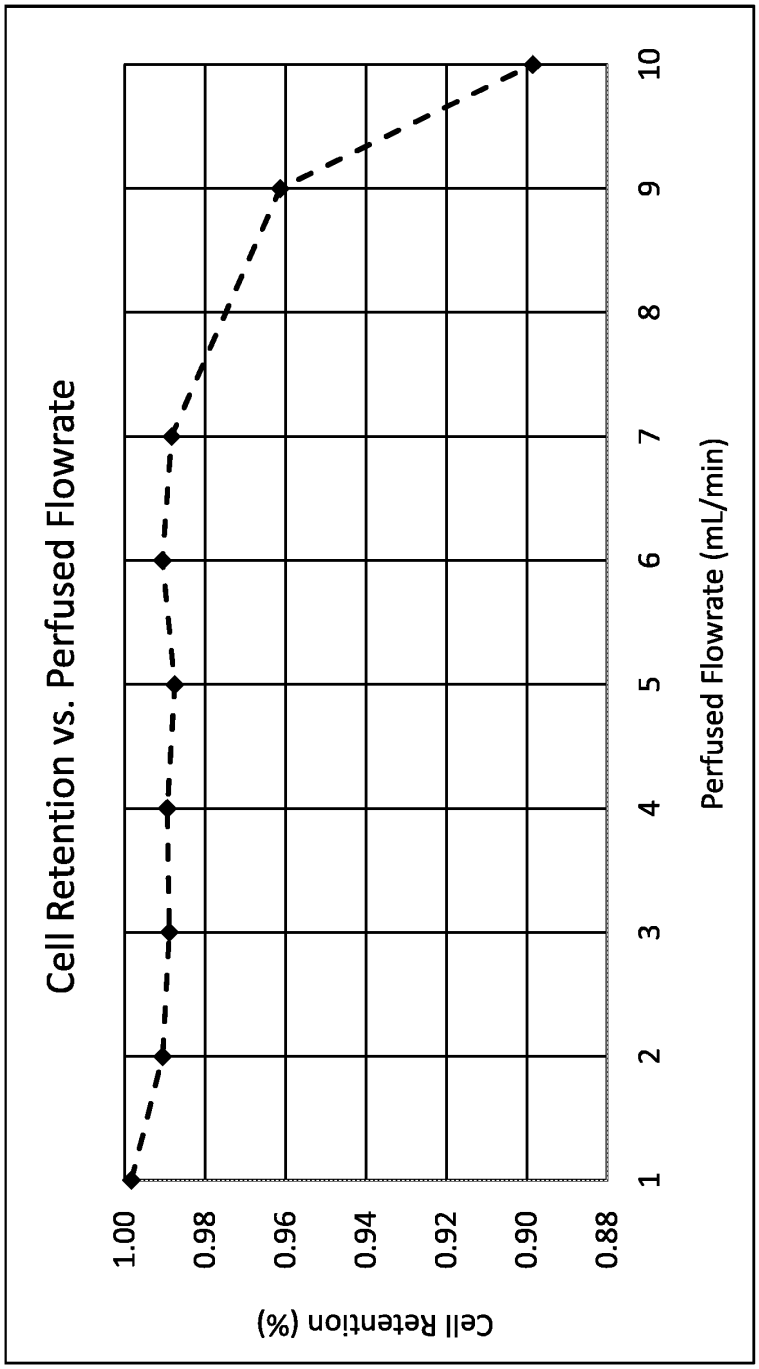

Cell Retention vs. Perfused Flowrate
Cell Retention (%)
1.00
0.98
0.96
0.94
0.92
0.90
0.88
Perfused Flowrate (mL/min)
1
2
3
4
5
6
7
8
9
10

FIG. 23

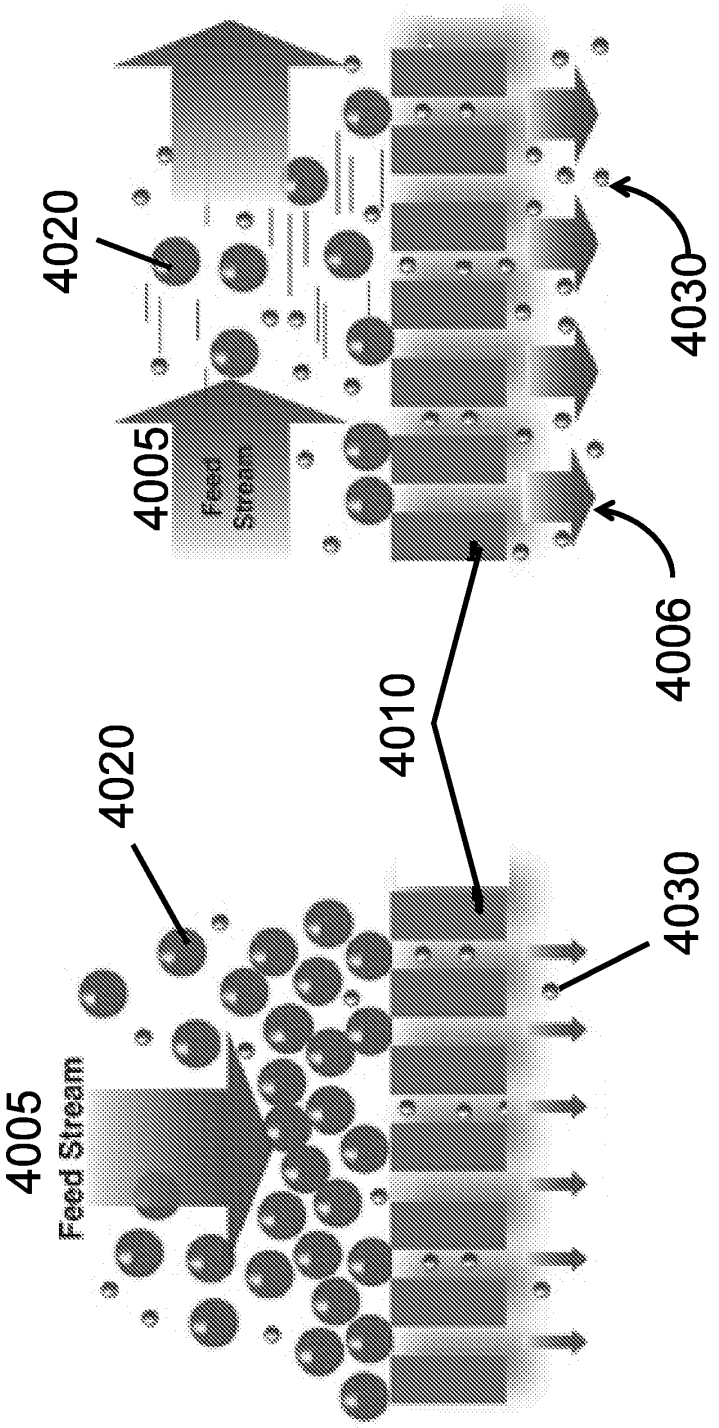

4020
4005
Feed Stream
4030
4006
4010
4020
4030
4005
Feed Stream

FIG. 24

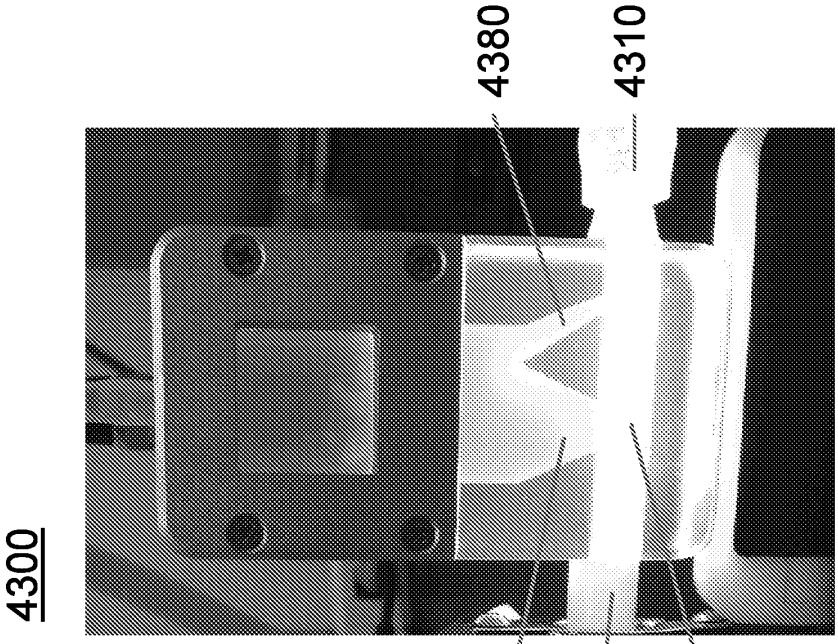

4300
4380
4310
4390
4330
4340

FIG. 26

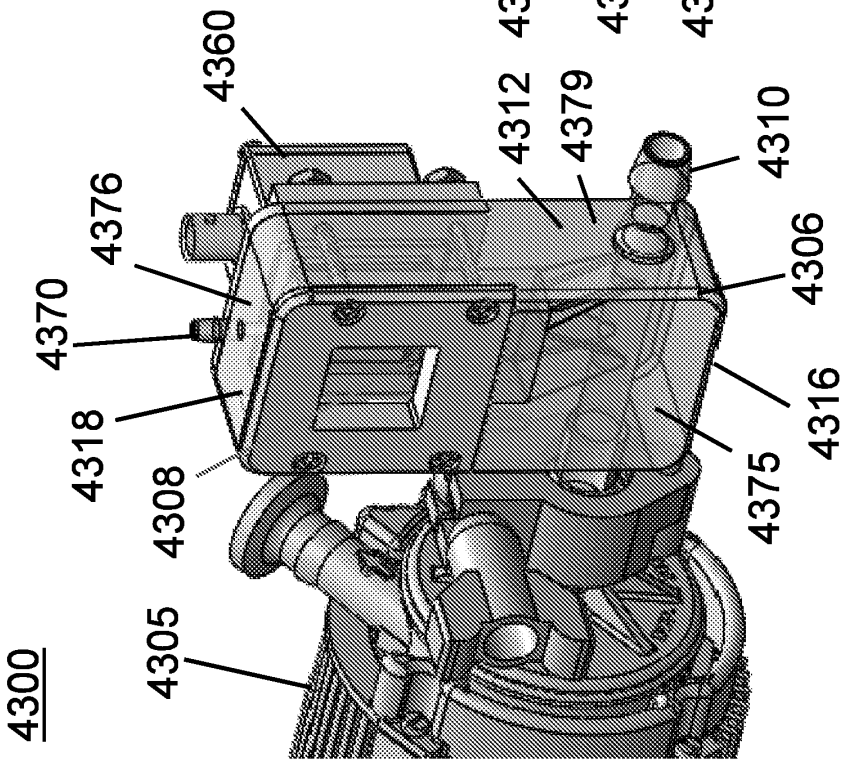

4300
4305
4308
4318
4370
4376
4360
4312
4379
4310
4306
4316
4375

FIG. 25

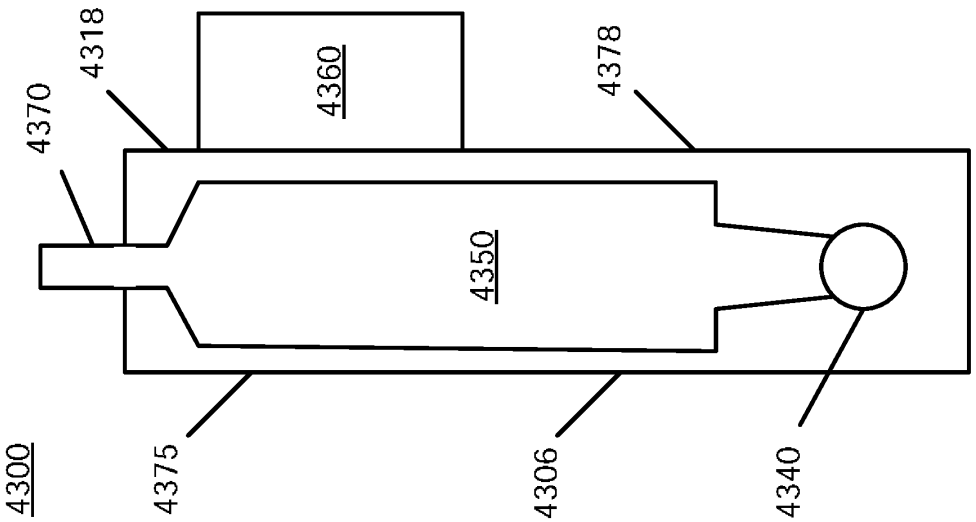


FIG. 27

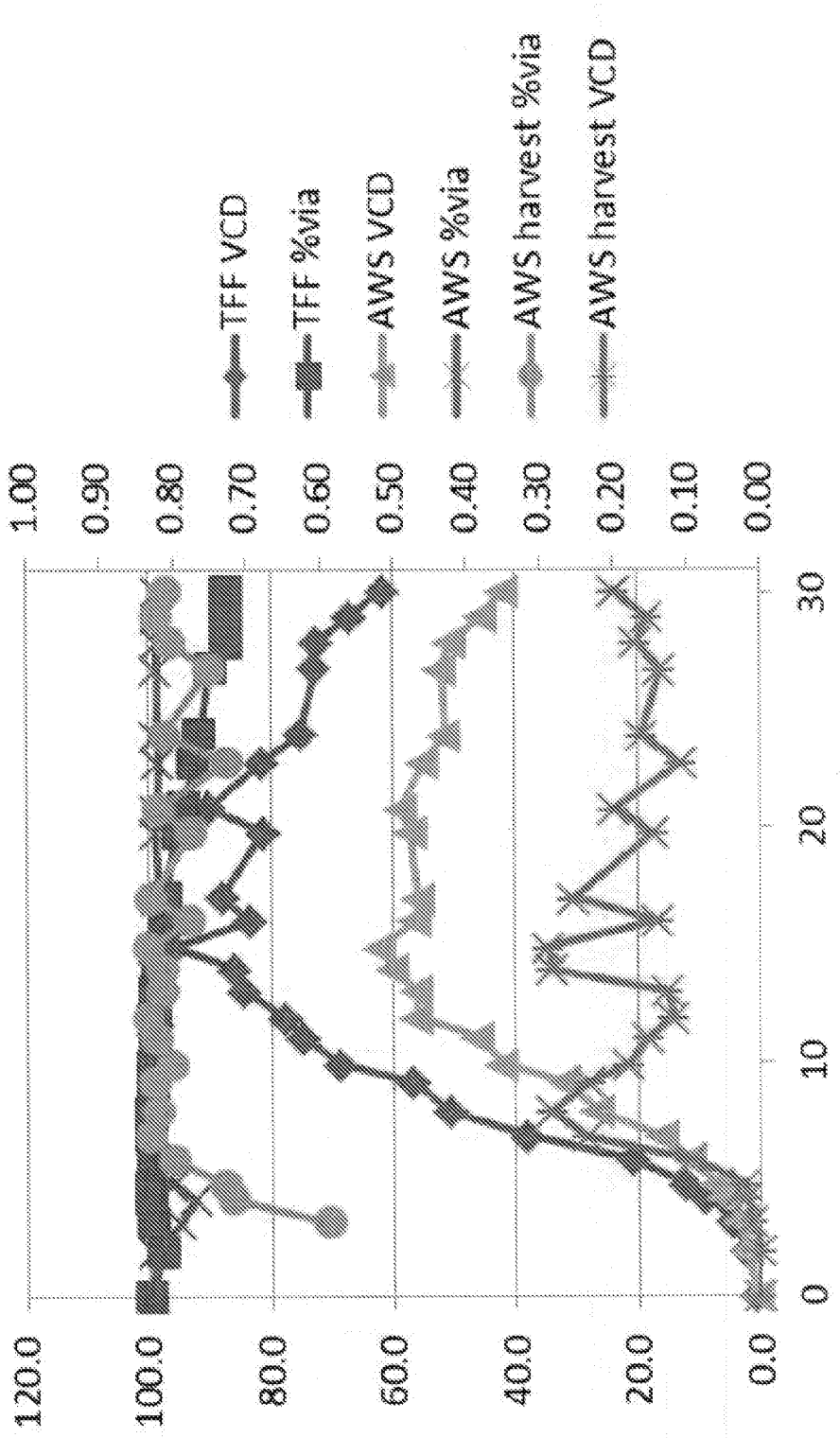

TFF VCD
TFF %via
AWS VCD
AWS %via
AWS harvest %via
AWS harvest VCD
120.0
100.0
80.0
60.0
40.0
20.0
0.0
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
10
20
30

FIG. 28

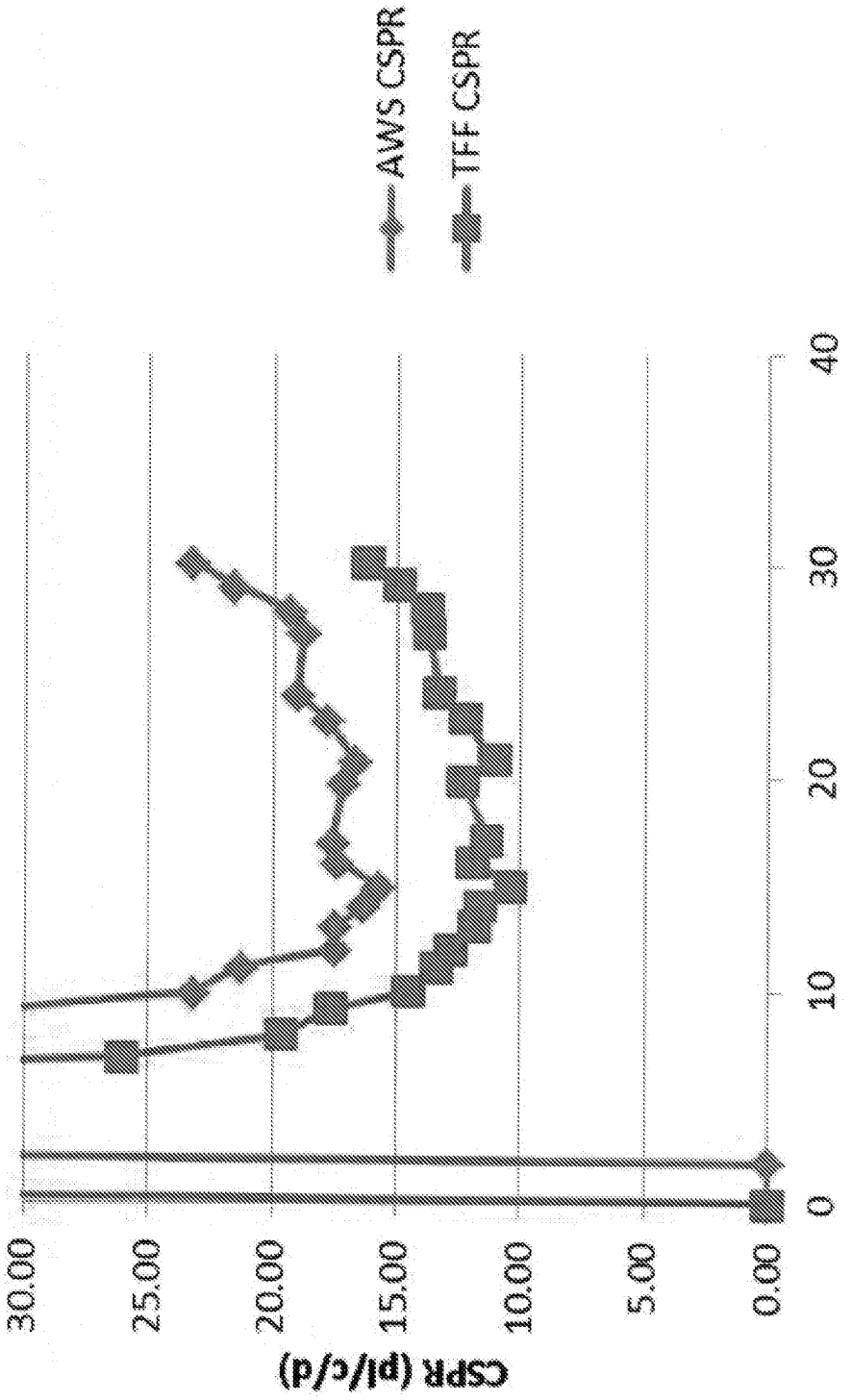

AWS CSPR
TFF CSPR
CSPR (pl/c/d)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
10
20
30
40

FIG. 29

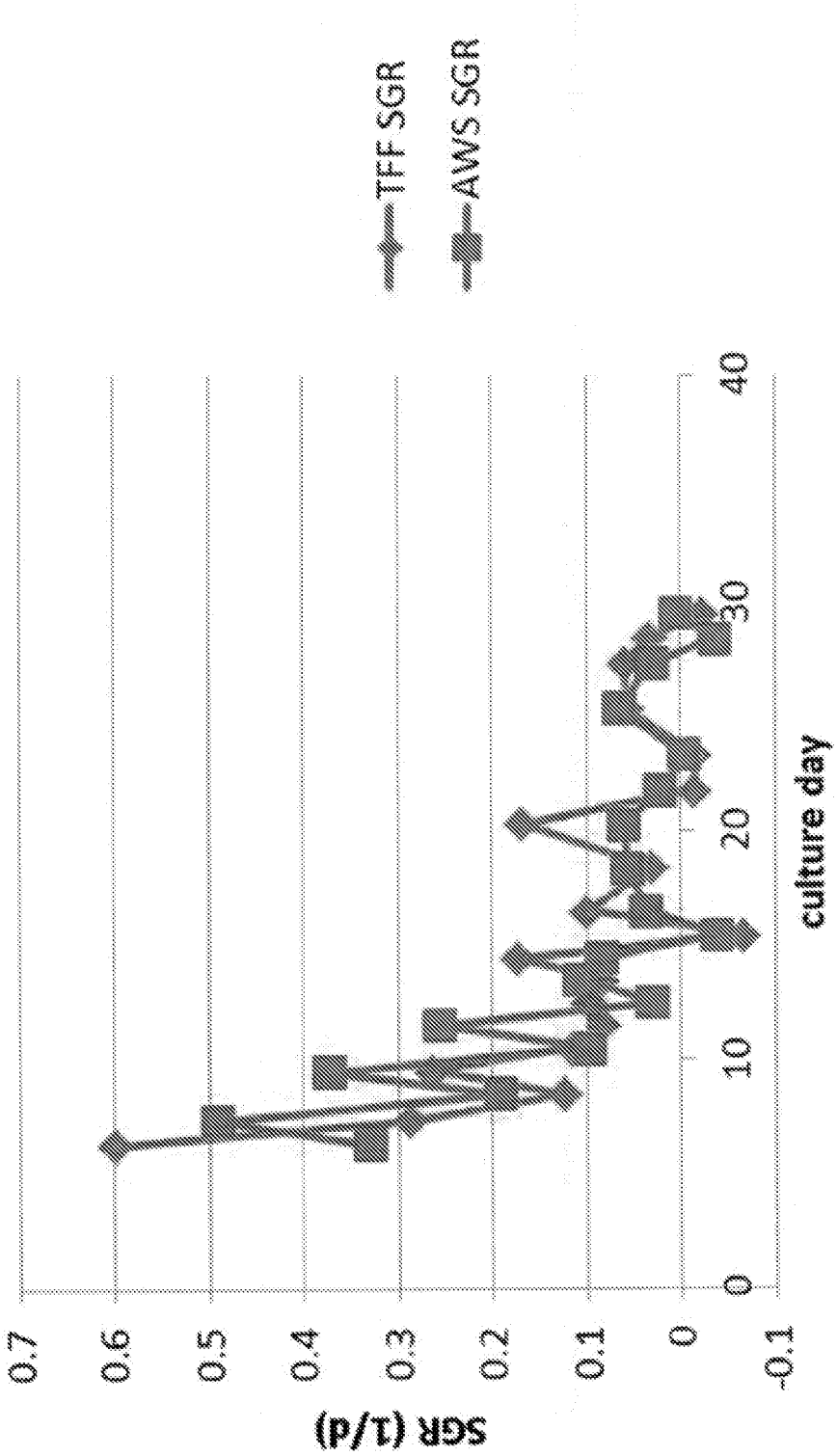

TFF SGR
AWS SGR
SGR (1/d)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
10
20
30
40
culture day

FIG. 30

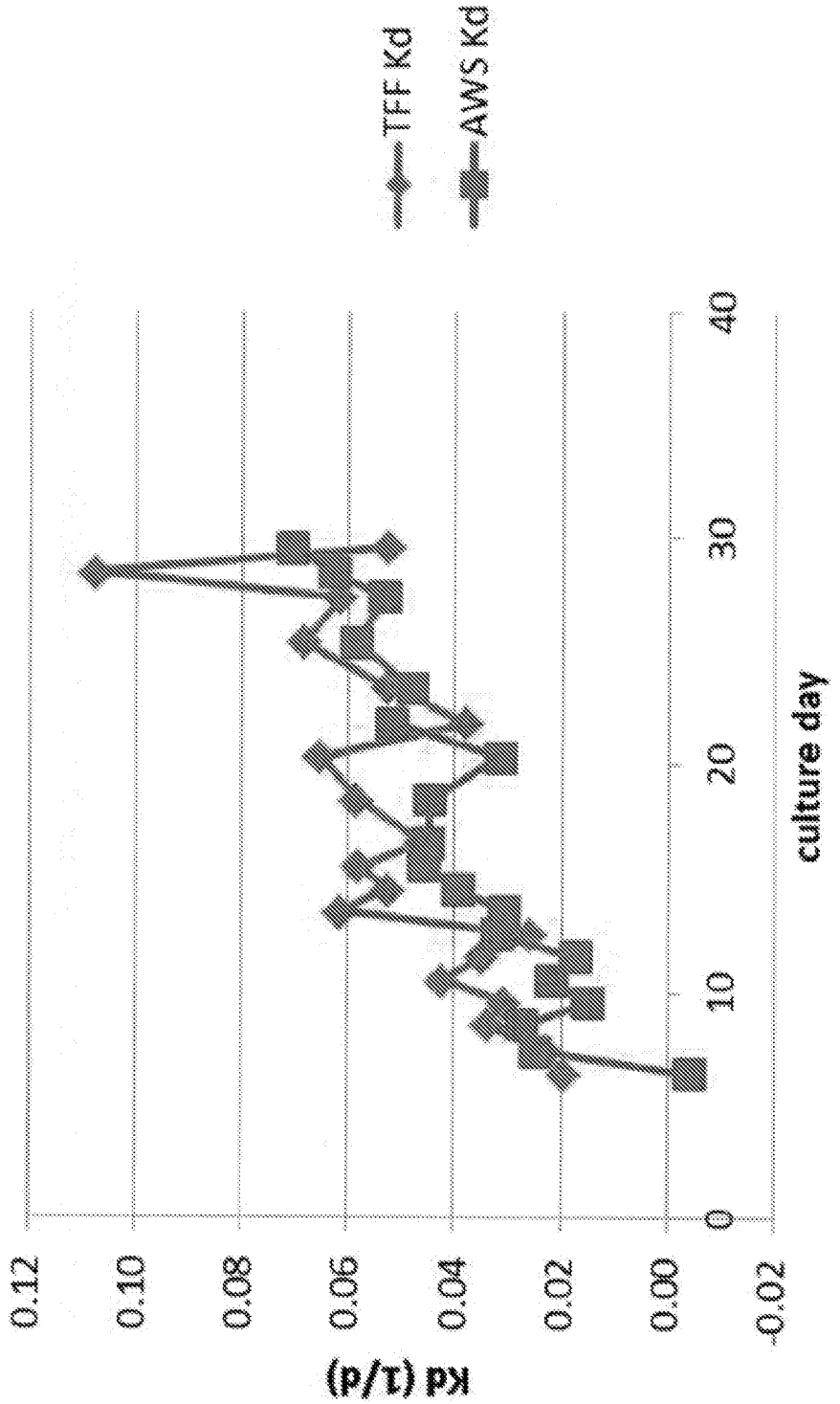

TFF Kd
AWS Kd
kd (1/d)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
0
10
20
30
40
culture day

FIG. 31

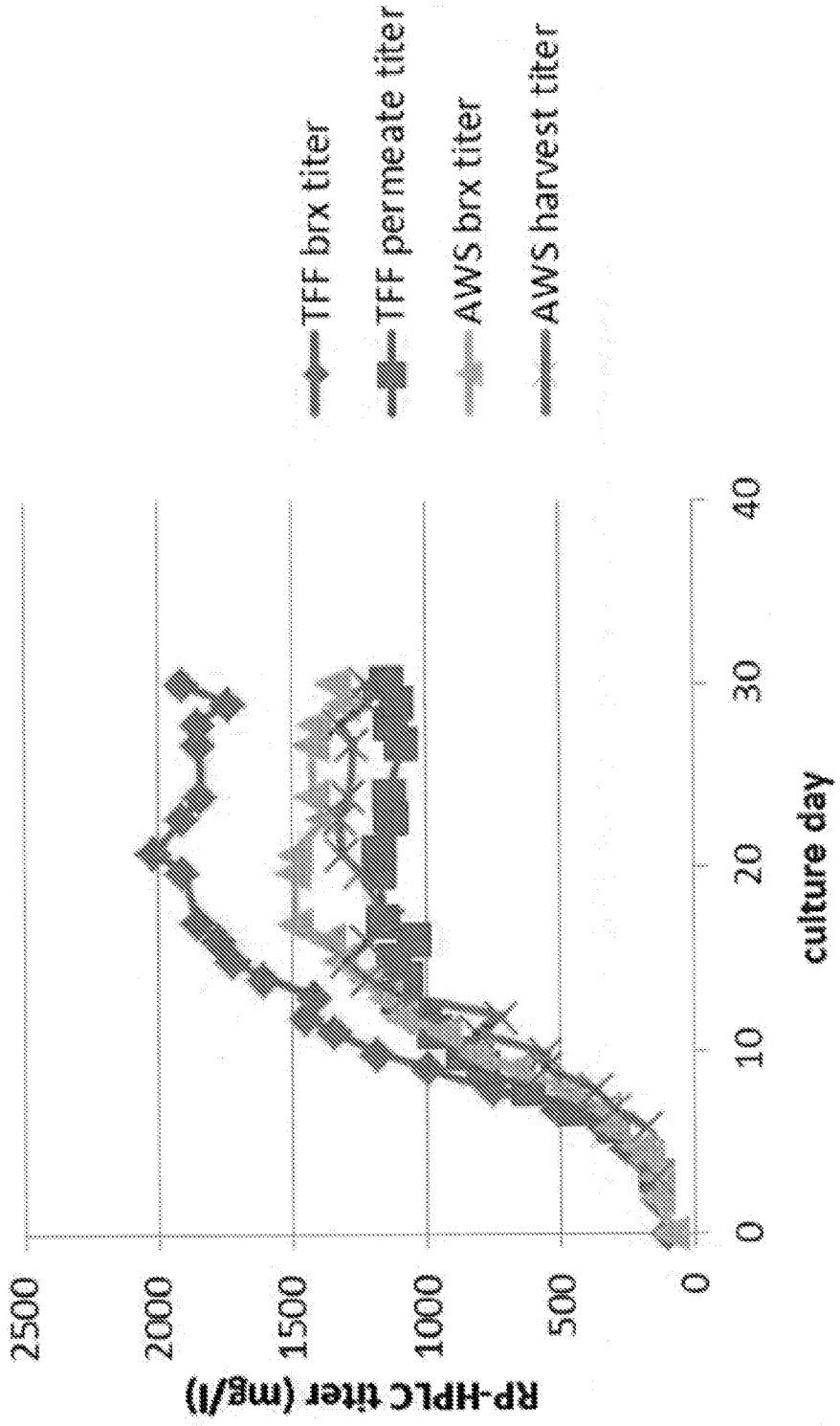

TFF brx titer
TFF permeate titer
AWS brx titer
AWS harvest titer
RP-HPLC titer (mg/l)
2500
2000
1500
1000
500
0
0
10
20
30
40
culture day

FIG. 32

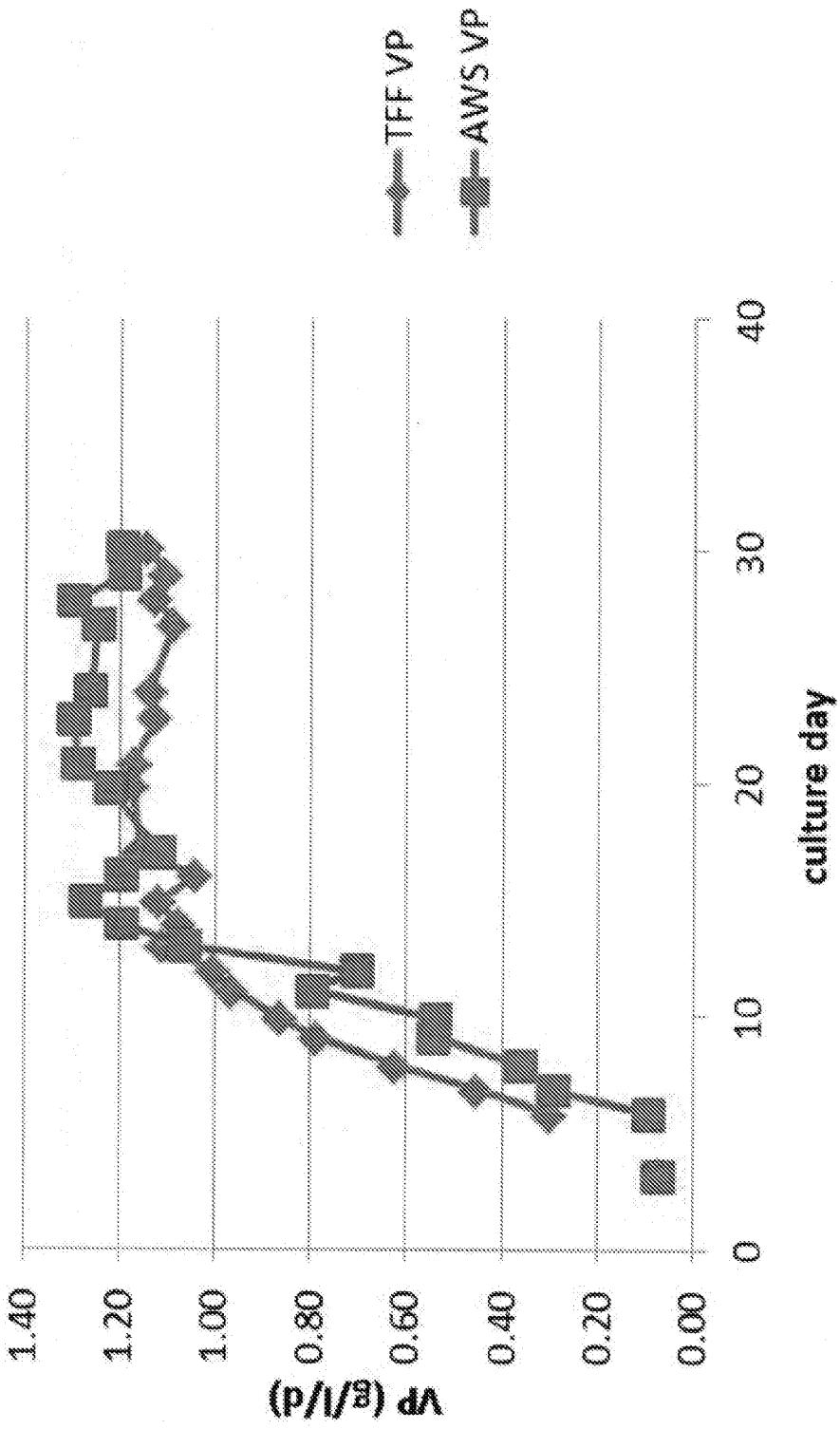

TFF VP
AWS VP
VP (g/l/d)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
10
20
30
40
culture day

FIG. 33

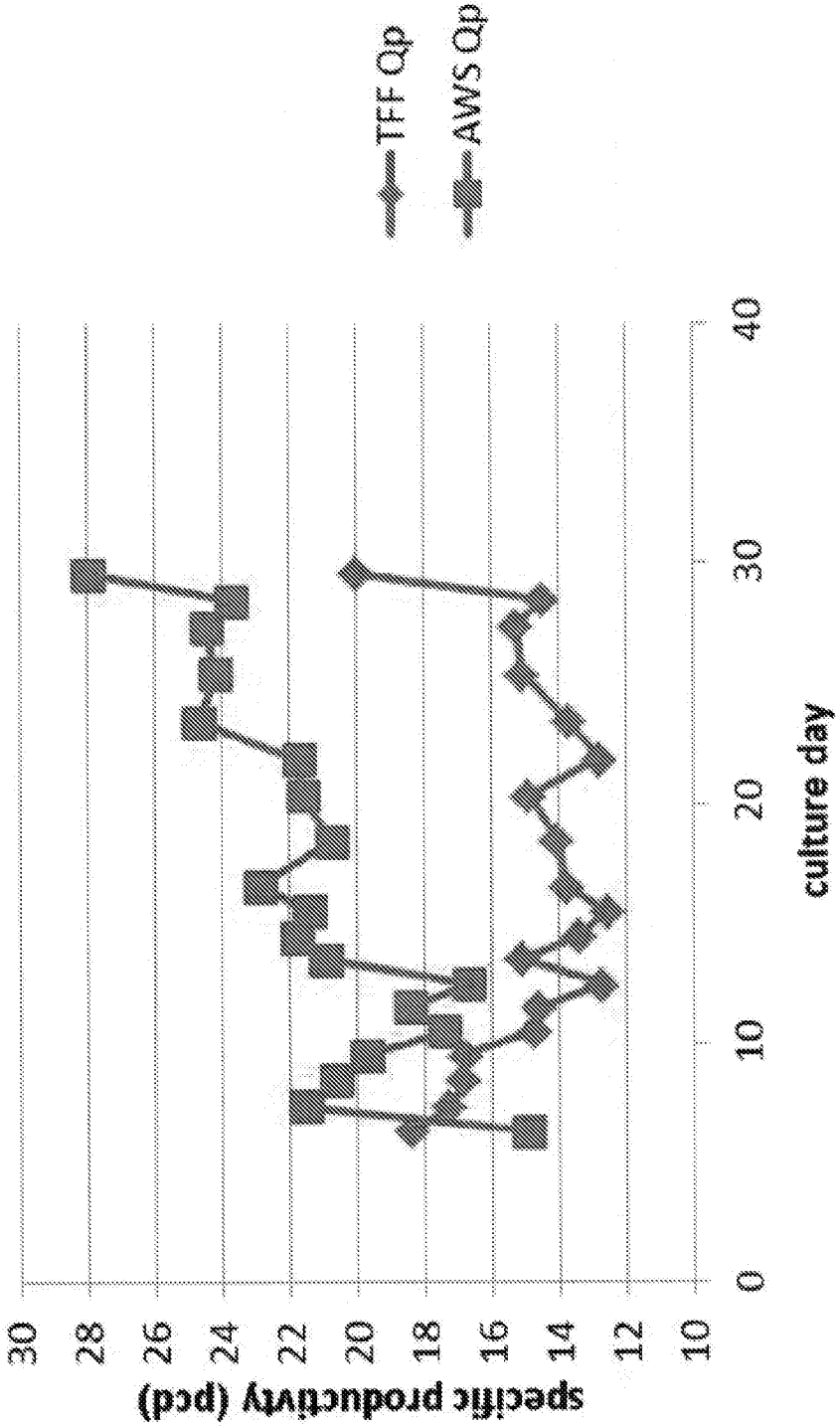

TFF Qp
AWS Qp
specific productivity (pcd)
30
28
26
24
22
20
18
16
14
12
10
0
10
20
30
40
culture day

FIG. 34

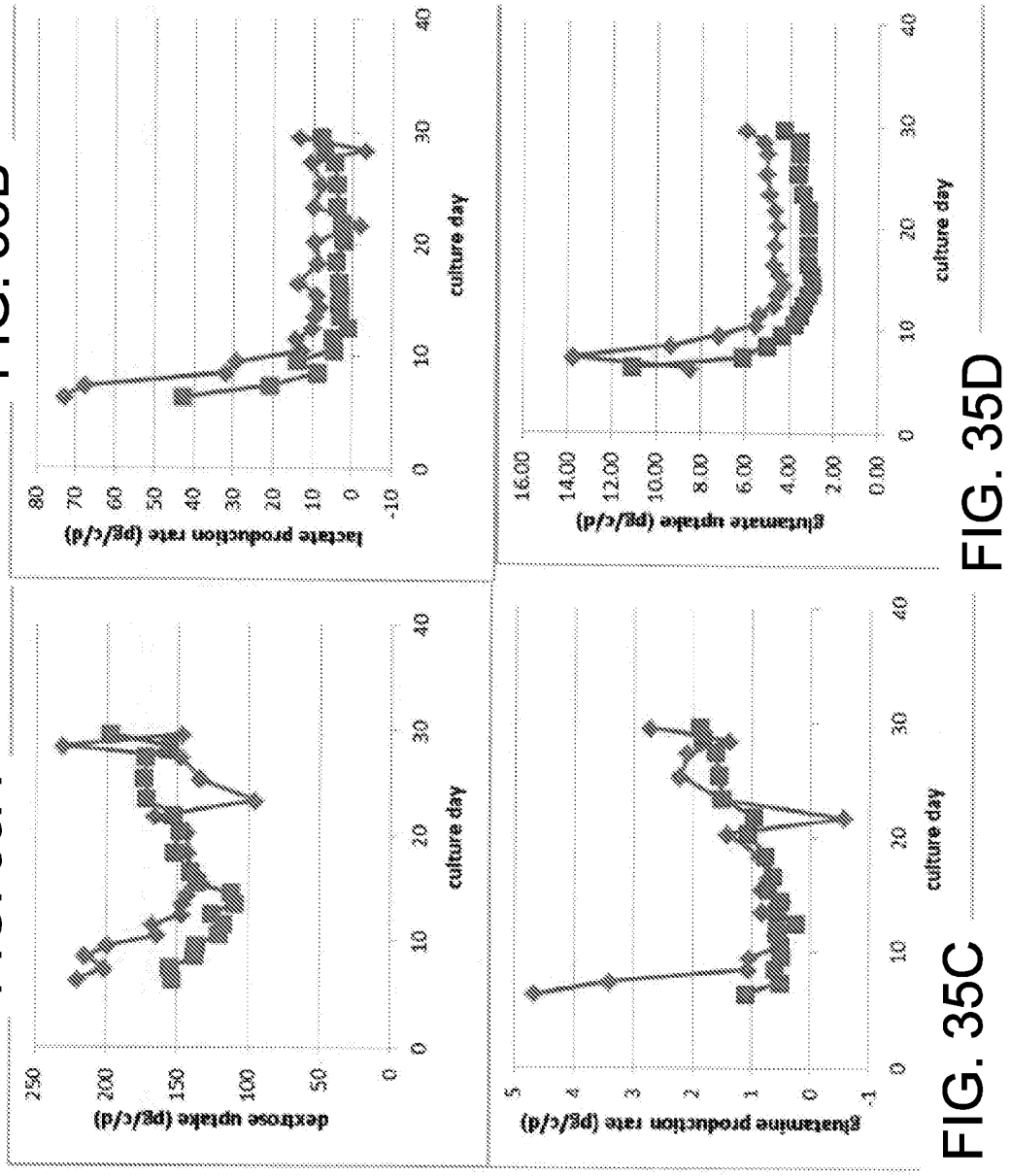


FIG. 35A

FIG. 35B

FIG. 35C

FIG. 35D

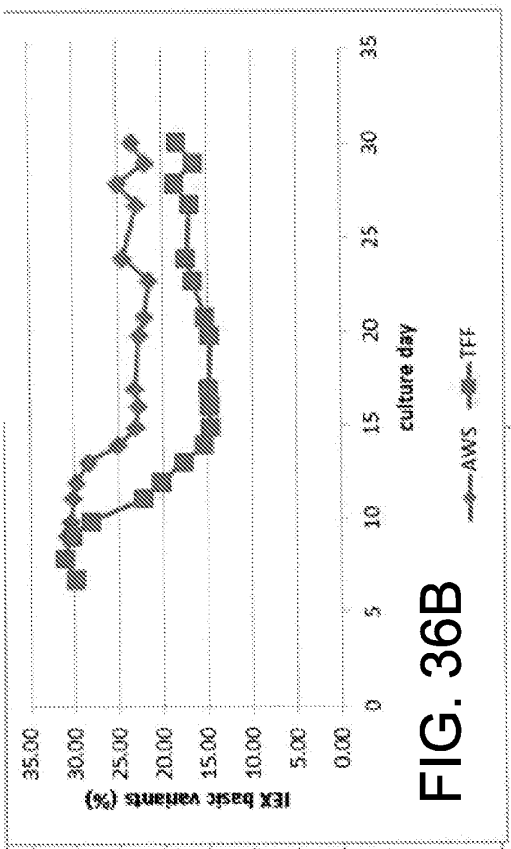


FIG. 36B

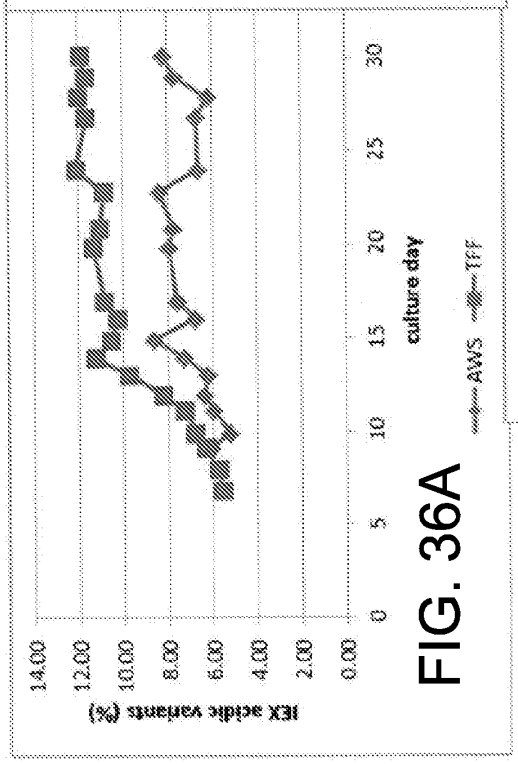


FIG. 36A

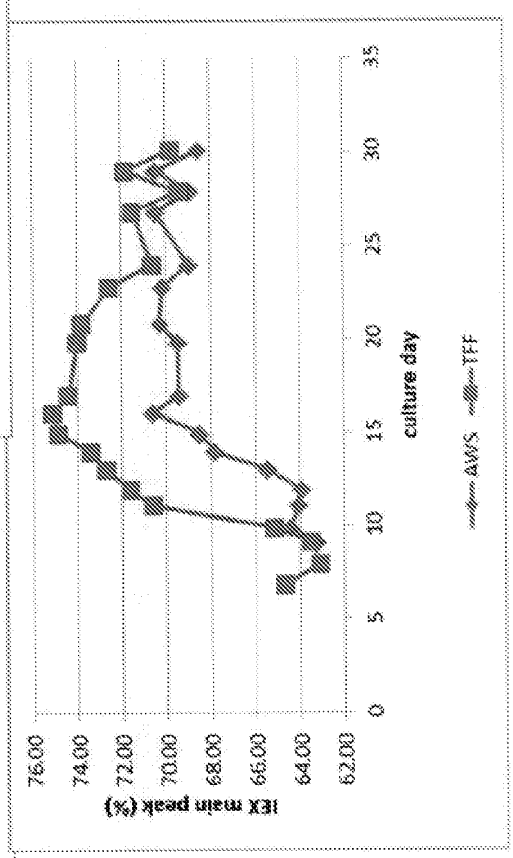


FIG. 36C

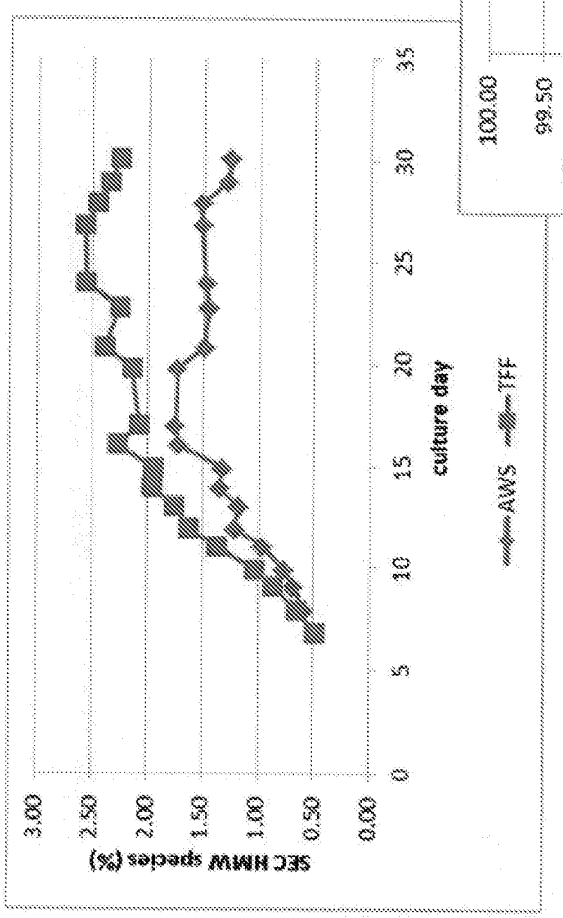


FIG. 37A

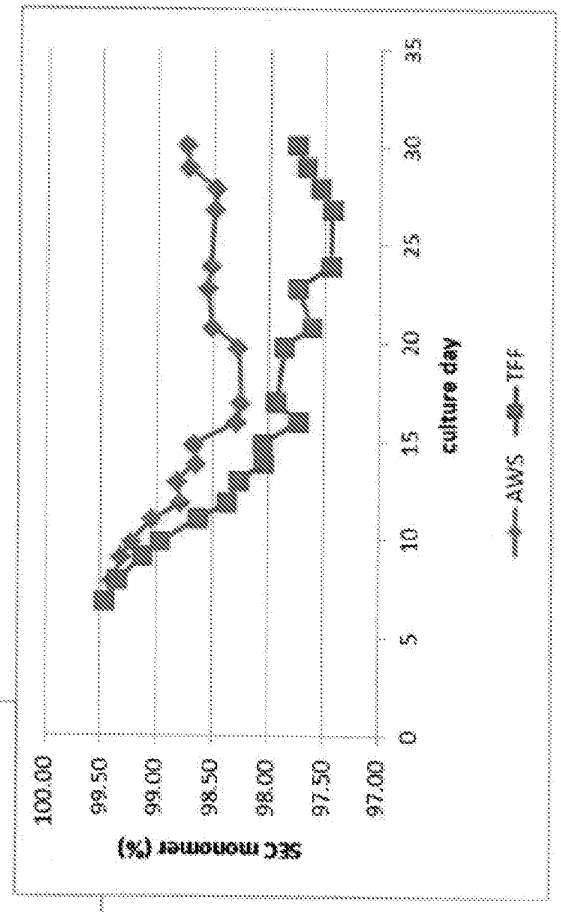


FIG. 37B

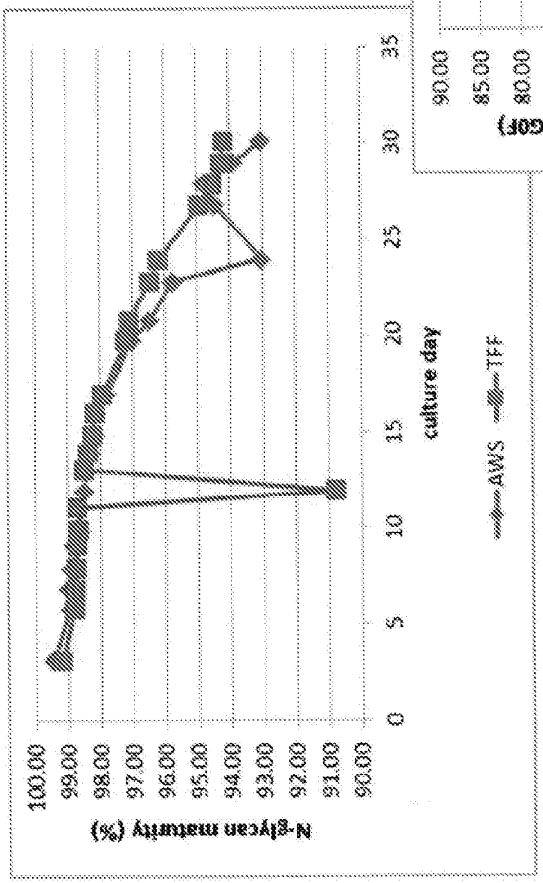


FIG. 38A

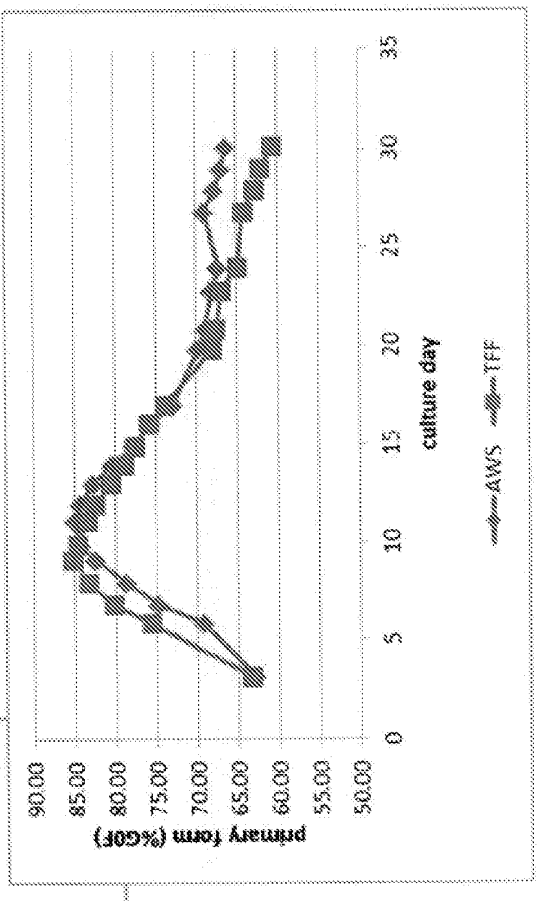


FIG. 38B

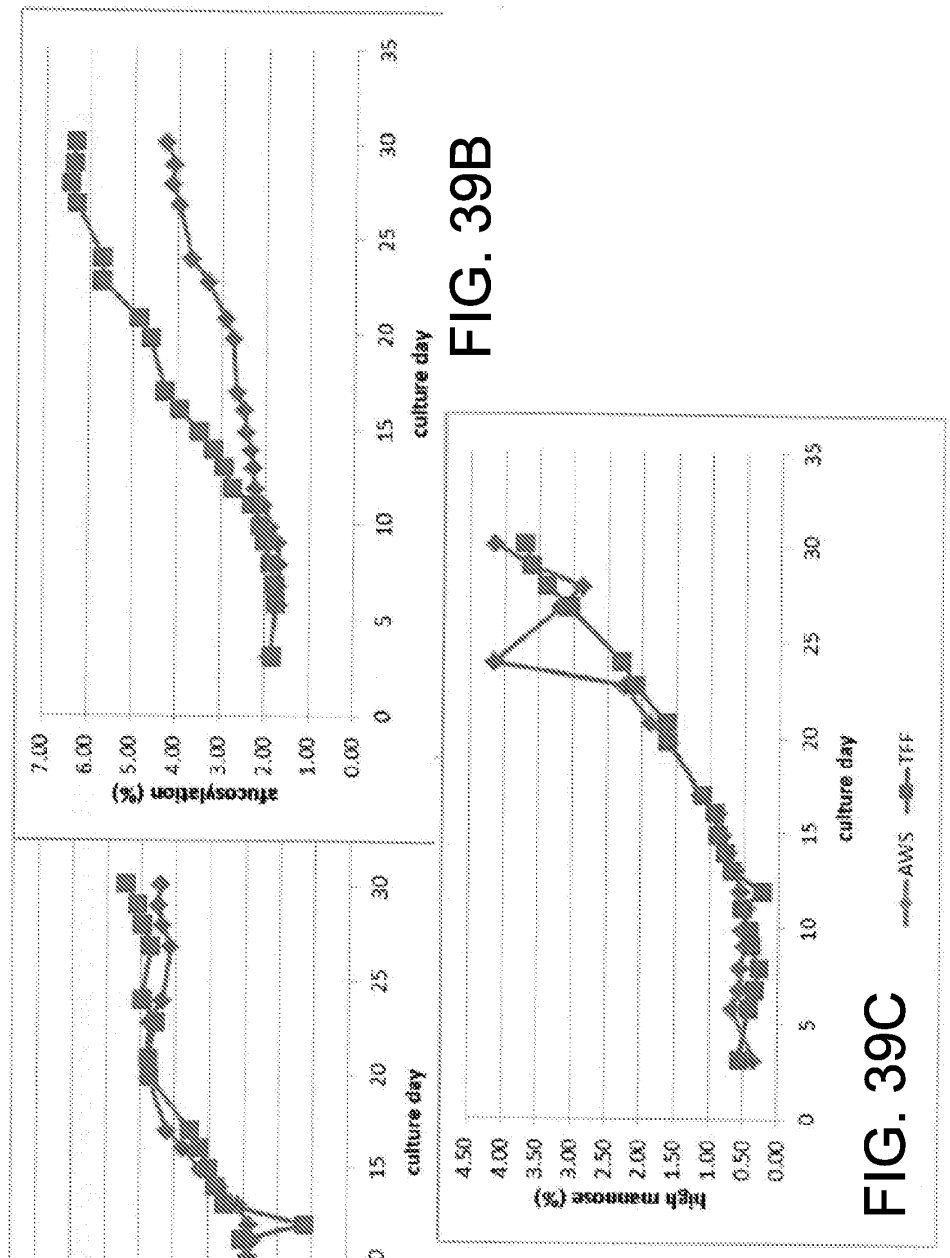


FIG. 39A

FIG. 39B

FIG. 39C

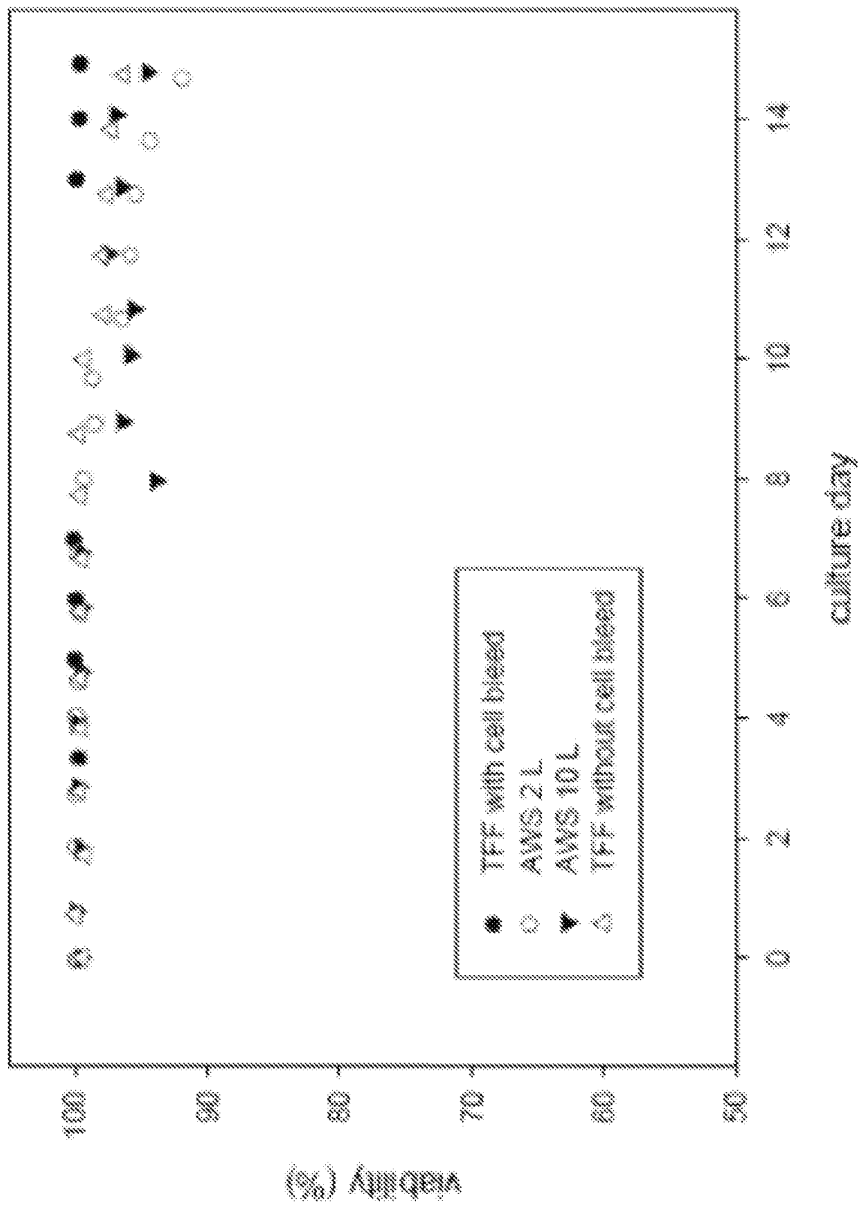

viability (%)
100
90
80
70
60
50
0
2
4
6
8
10
12
14
culture day
TFF with cell bleed
AWS 2 L
AWS 10 L
TFF without cell bleed

FIG. 40