Optimization of UGS operation processes

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Target: Minimize inputs injecting and producing gas in UGS

Problem:
Distribution of the preset injection and production volumes of gas

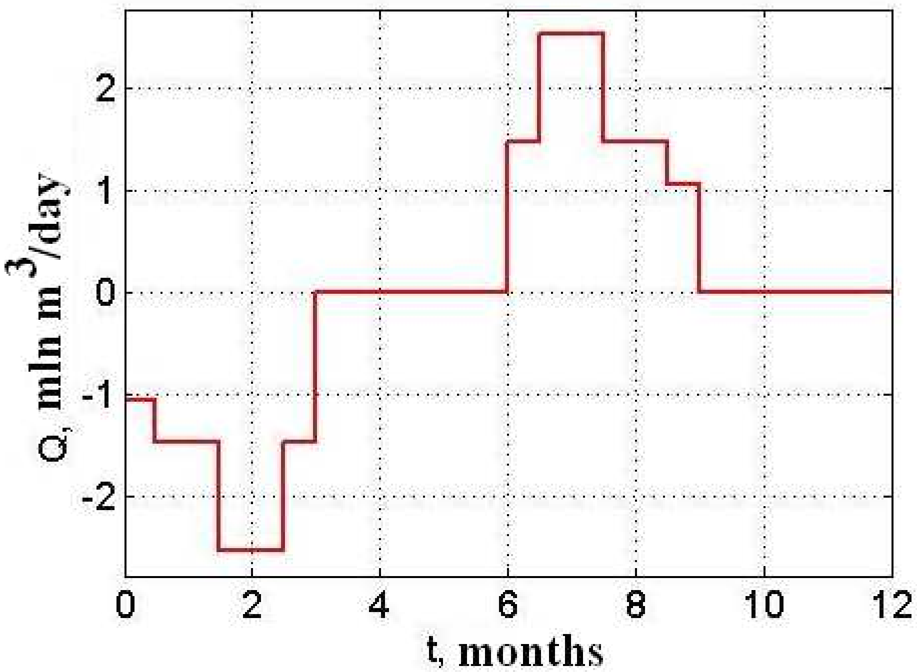
Optimality criteria :
minimum watercut of well production,
minimum gas-water contact uprise at the gas production period,
maximum gas-water contact remoteness from well bottoms

Initial data

1. Numerical model of the UGS active field;

2. Limits (max и min) production rates and wells injectivity well spacing, perforation intervals;

3. Time changes of injection and production volumes for all the UGS object (Q_t):



$Q_t>0$ – gas production

$Q_t<0$ – gas injection

example

Required parameters:

qwt – injection volume (qwt <0) or production volume of gas (qwt >0) for well number w at t-period, w=1,2,…,W; t=1,2,…,T, where W – number of wells, T – number of periods

Examples:

W=7, T=24, so the duration of the period is 2 weeks, the UGS operation cycle – 1 year

Initial solution: qwt=Qt/W, w=1,2,…,W; t=1,2,…,T, equal injection and production volumes for all wells

Solution Schem

Volumes calculation

Objective function – $F(q_{11},\dots,q_{WT})$

(hydrodynamic box - Eclipse)

$F(q_{11i},\dots,q_{WTi})$

i - № итерации

$q_{11i+1},\dots,q_{WTi+1}$,

Required parameters changes

(optimization box - Matlab)

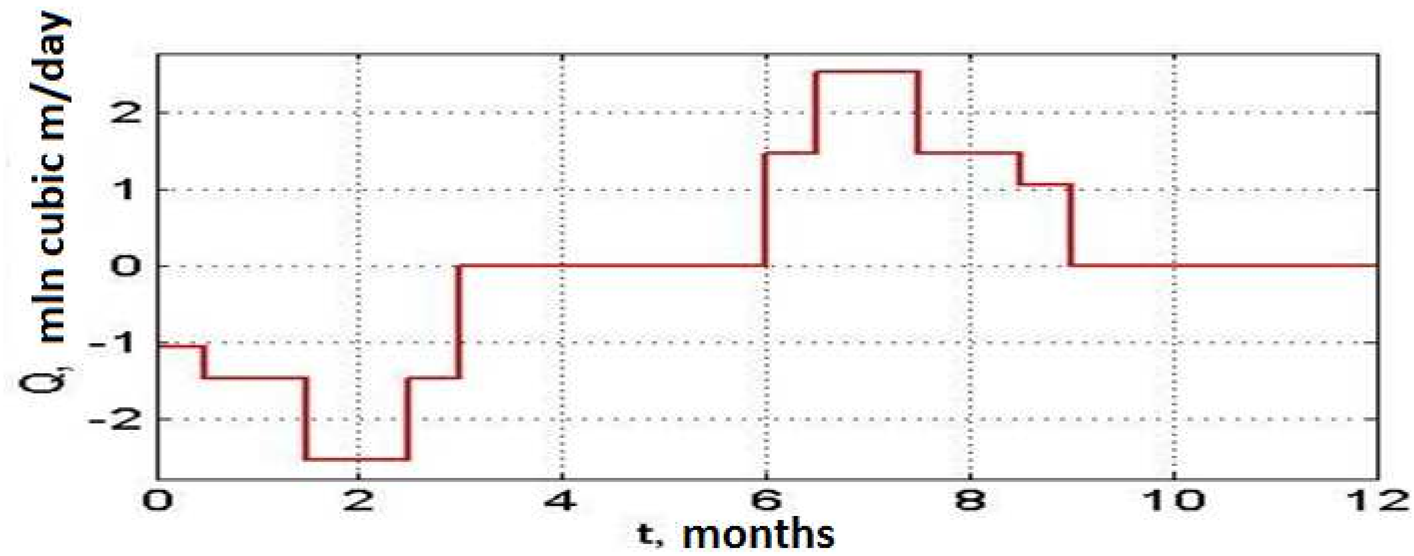
$abs(F(q_{11i},\dots,q_{WTi}) - F(q_{11i+1},\dots,q_{WTi+1})) < \varepsilon$ ⇨ stop

Examples

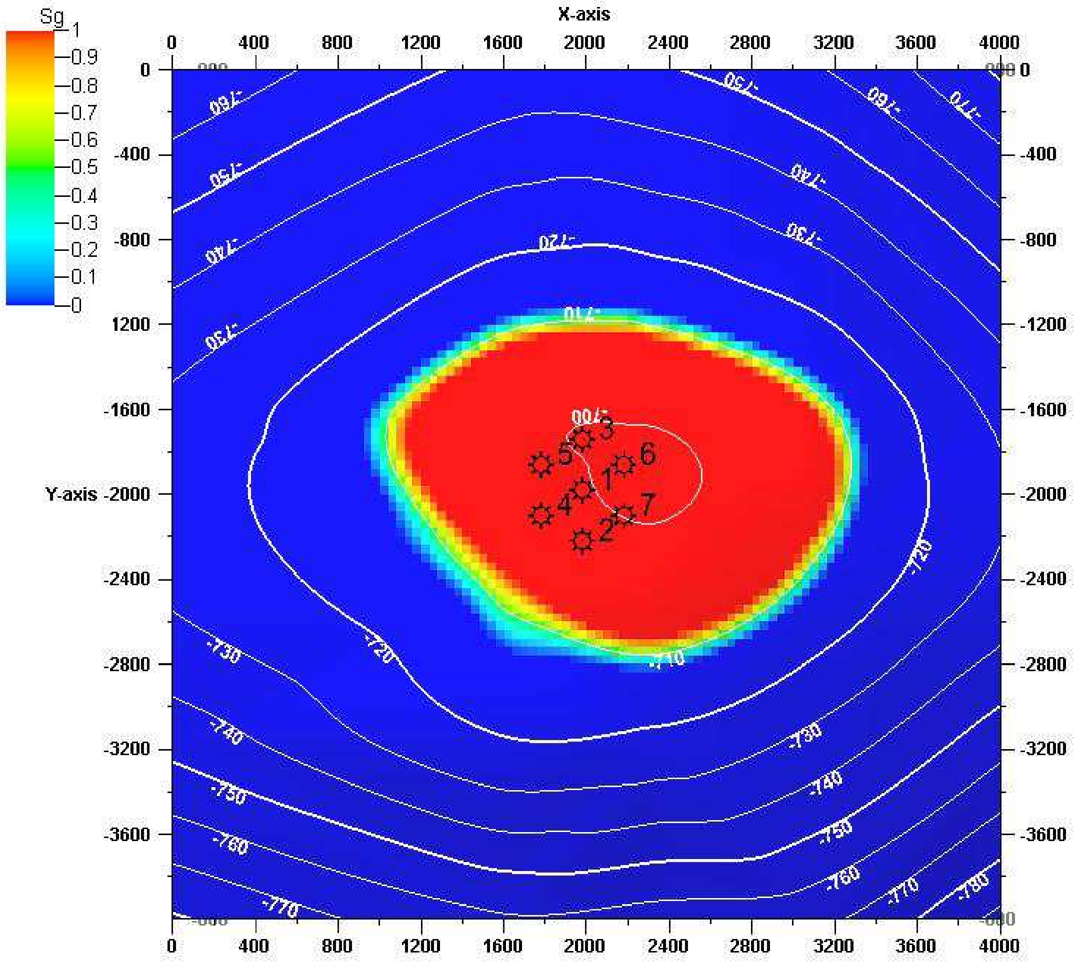
Initial Data:

Cushion gas volume - 112,35 mln m^3;
Active gas volume - 147,00 mln m^3;
Initial bottom-hole pressure - 7 MPa;
Nimber of wells (W) - 7;
Number of periods (T) – 24 (UGS operation cycle – 1 year);
Duration of the period – 2 weeks;
Duration of injection, production and shut down stages– 3 months

Time changes of injection and production volumes all over the UGS:



Structure map, wells disposition and initial external boundary) (color shows gas saturation)



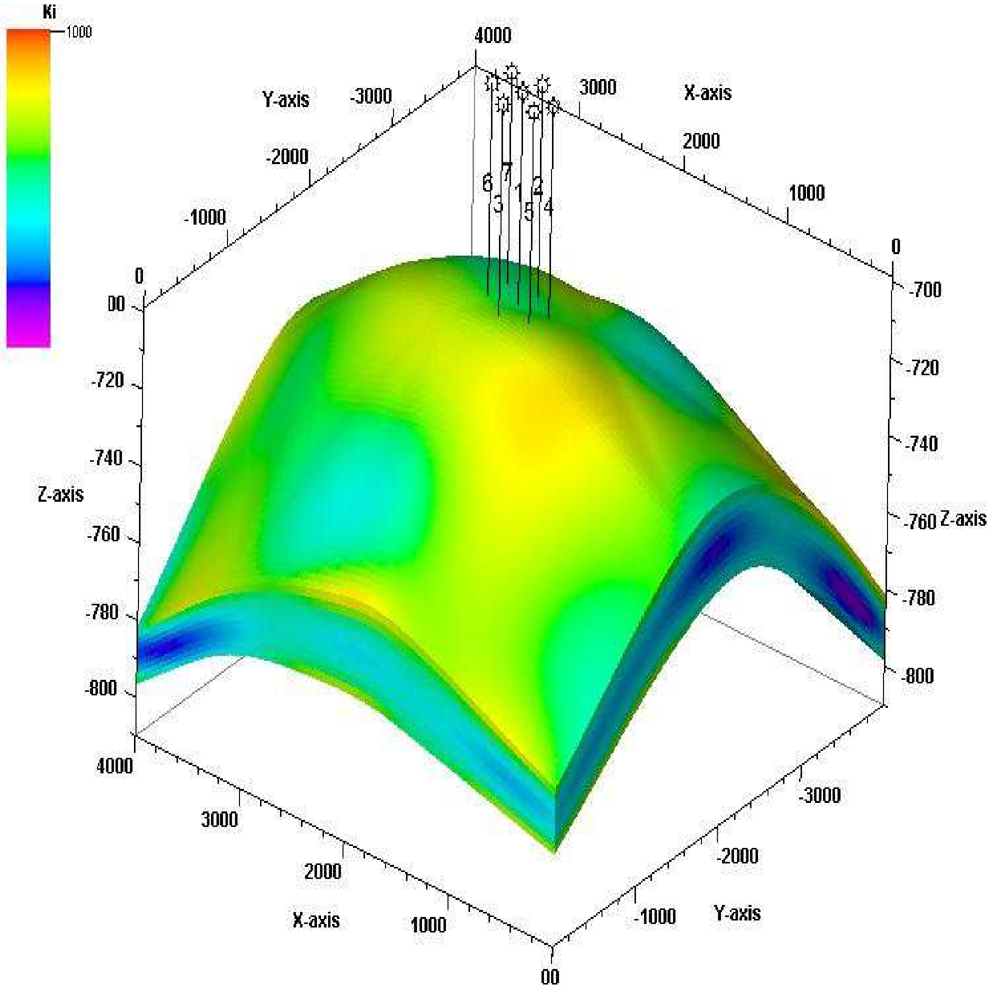
Wells data

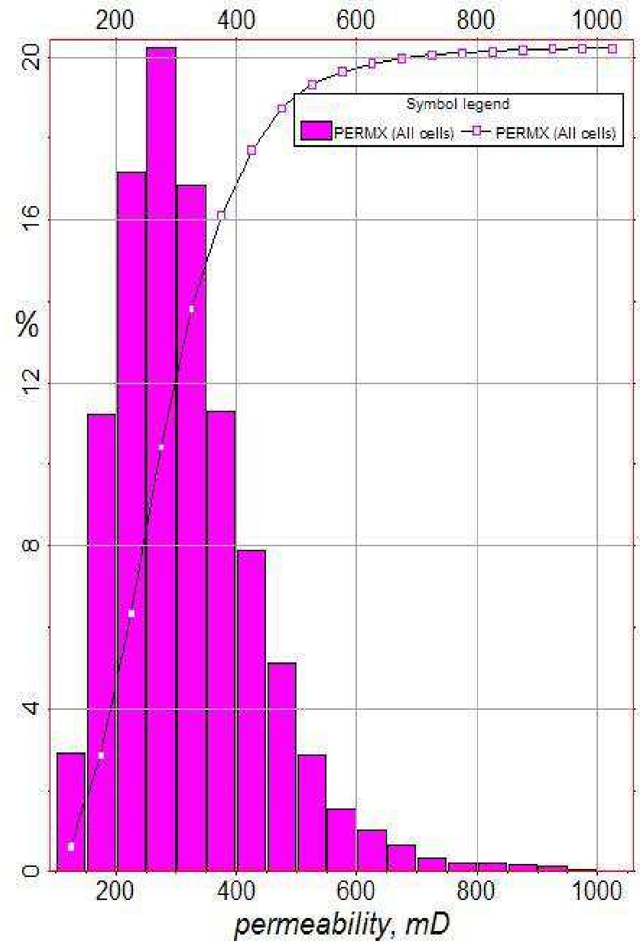
№ well	Top of well coordinates		Perfotaion intervals	
	X, m	Y, m	Z1	Z2
1	1980	-1979	-700.52	-706
2	1980	-2219	-702.4	-708
3	1980	-1739	-699.8	- 705.1
4	1780	-2099	-703.4	- 708.9
5	1780	-1859	-700.9	- 706.3
6	2180	-1859	-699	- 704.3
7	2180	-2099	-699.9	- 705.4

Wells disposition and perforation intervals data

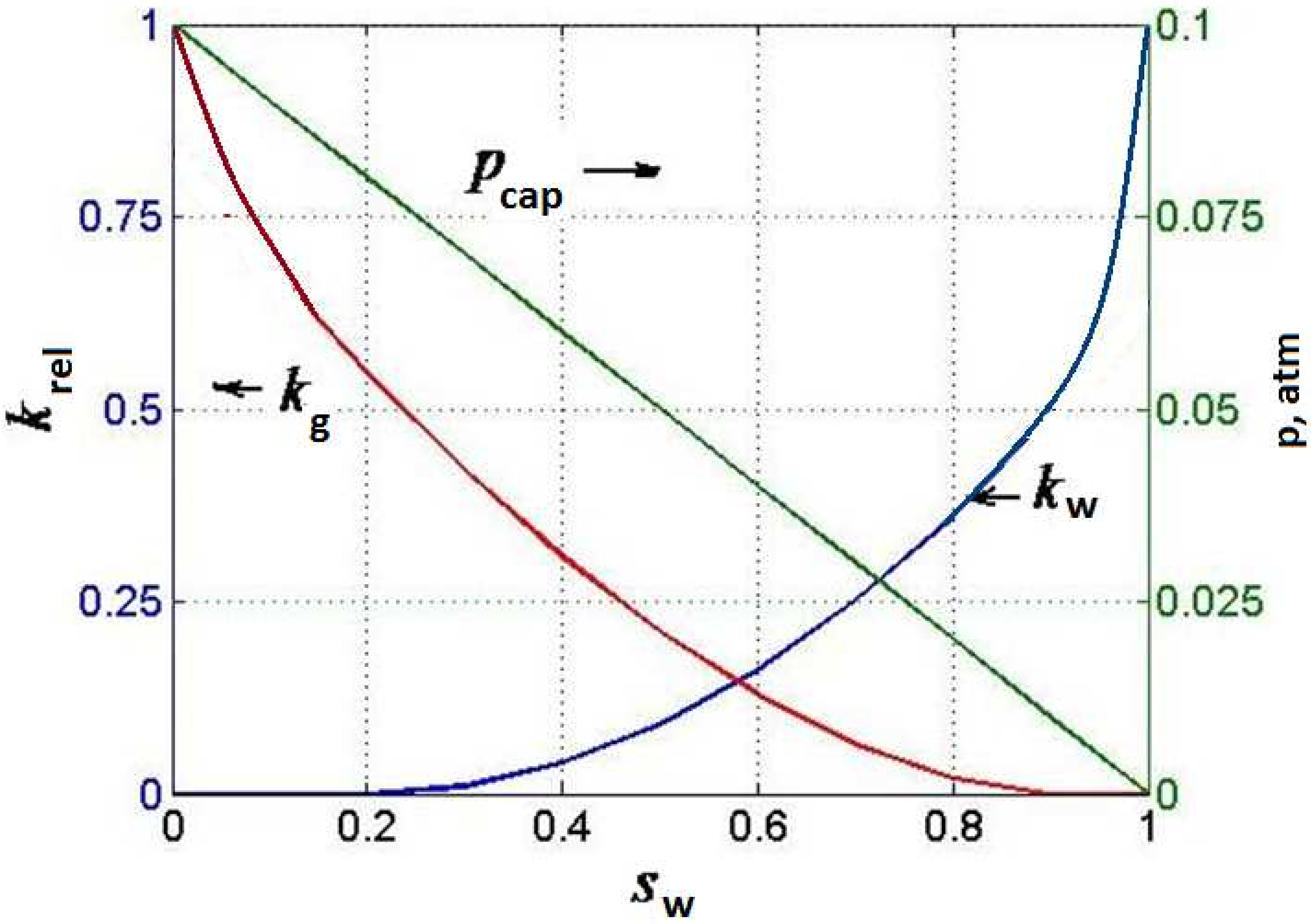
. Well number	Coordinates of well-spring		Perforation interval	
	X, м	Y, м	Z1	Z2
1	1980	-1979	-700.52	-706
2	1980	-2219	-702.4	-708
3	1980	-1739	-699.8	-705.1
4	1780	-2099	-703.4	-708.9
5	1780	-1859	-700.9	-706.3
6	2180	-1859	-699	-704.3
7	2180	-2099	-699.9	-705.4

Permeability distribution





Relative phase permeability and and capillary pressure



Example 1 **Objective function: F() – cumulative water production volume for the UGS wells after a year cycle operation: $F(q_{11},\dots,q_{WT}) \rightarrow \min$**

$u_{wt}=q_{wt}/Q_t$ (relative volumes of injection and production)

Optimal relative volumes of injection

№ well w	injection № period, t 1	2	3	4	5	6	Cp. value
1	0.189	0.181	0.177	0.188	0.199	0.188	0.187
2	0.177	0.169	0.178	0.163	0.165	0.169	0.170
3	0.096	0.099	0.096	0.089	0.097	0.093	0.095
4	0.129	0.127	0.124	0.121	0.114	0.111	0.121
5	0.14	0.132	0.132	0.136	0.126	0.132	0.133
6	0.176	0.191	0.189	0.204	0.203	0.2	0.194
7	0.093	0.1	0.104	0.099	0.095	0.107	0.100

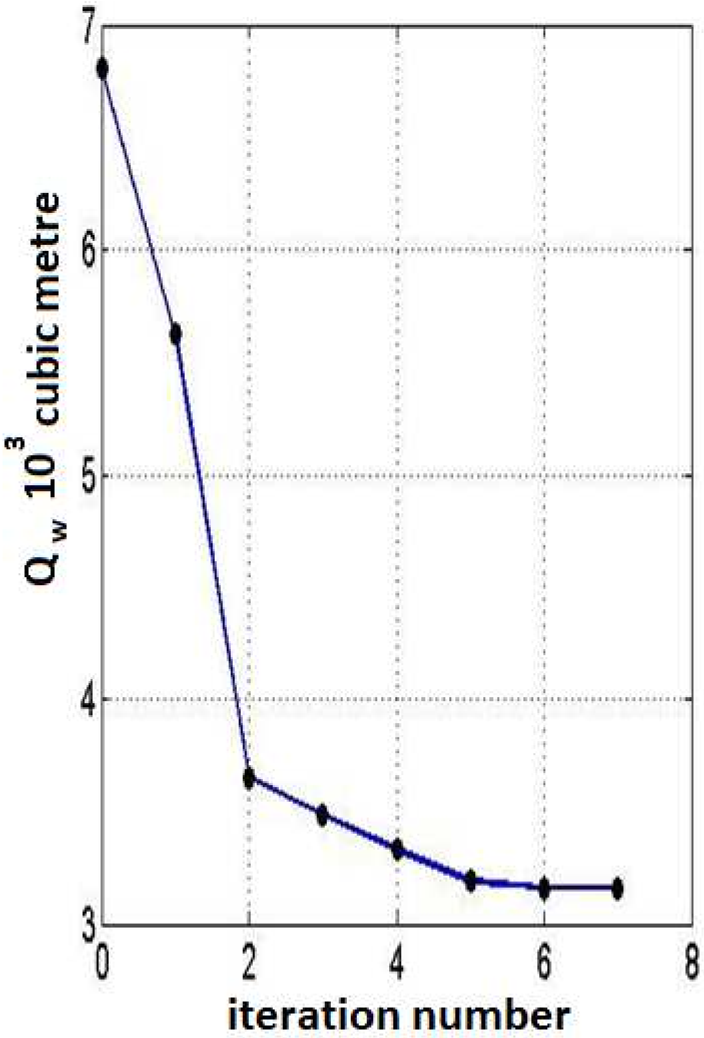
Optimal relative volumes of production

№ well w	production № period, t 13	14	15	16	17	18	Cp. value
1	0.175	0.162	0.166	0.154	0.151	0.15	0.160
2	0.102	0.094	0.097	0.097	0.091	0.094	0.096
3	0.154	0.166	0.158	0.153	0.14	0.156	0.155
4	0.079	0.074	0.062	0.076	0.088	0.09	0.078
5	0.13	0.124	0.147	0.158	0.162	0.152	0.146
6	0.215	0.216	0.215	0.215	0.215	0.215	0.215
7	0.145	0.165	0.155	0.147	0.151	0.142	0.151

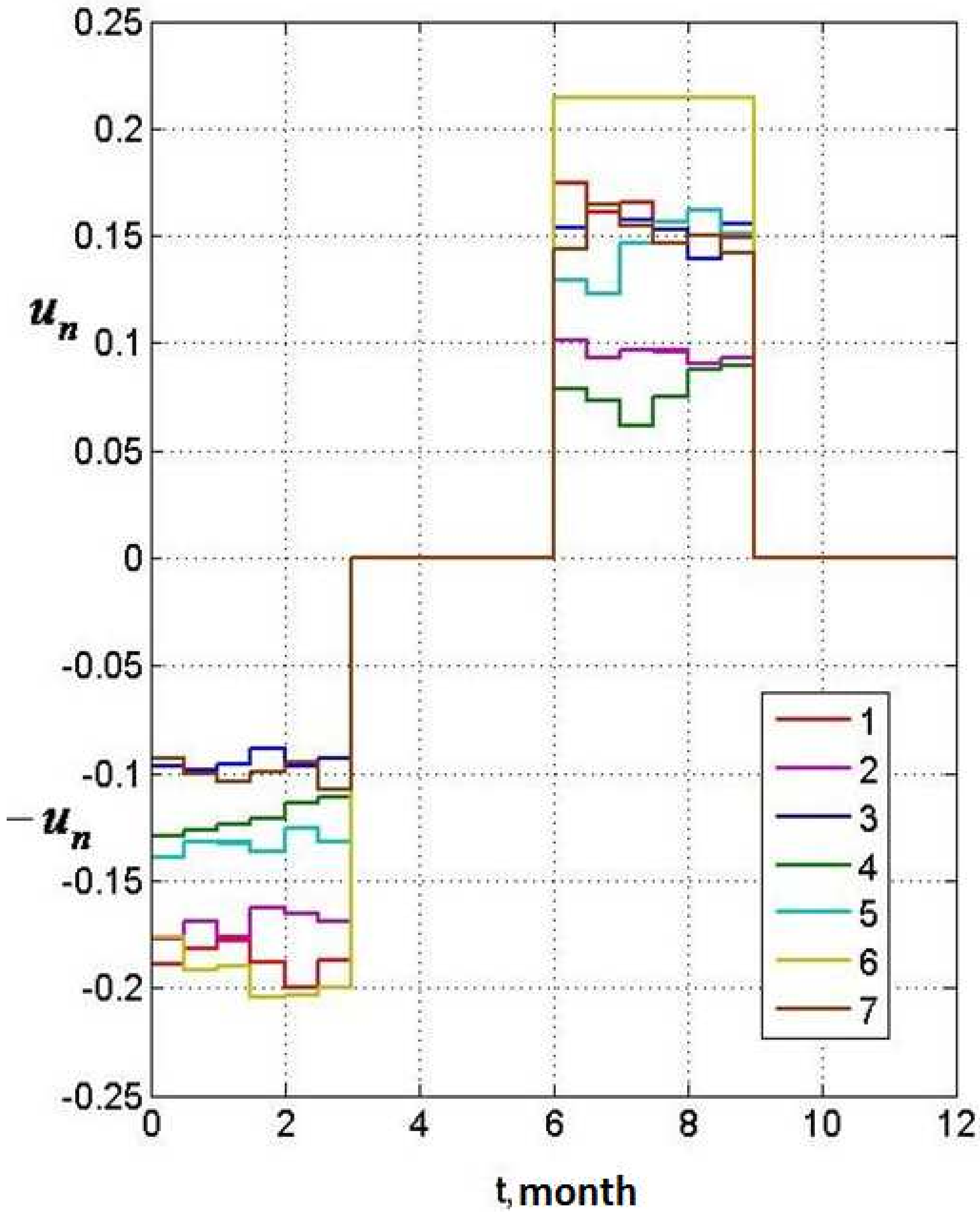
Cumulative gas injection and production volumes variation with time used in test calculations

Stage	*Q*, mln m^3/day	Stage	*Q*, mln m^3/day
1	-1.05	13	1.47
2	-1.47	14	2.52
3	-1.47	15	2.52
4	-2.52	16	1.47
5	-2.52	17	1.47
6	-1.47	18	1.05
7÷12	0.00	19÷24	0.00

Iteration changes of objective function (example 1)



Optimal solutions (example 1)



Dynamics of optimal production

Well number	Control step number						Cp. value
	Production						
	13	14	15	16	17	18	
1	0.175	0.162	0.166	0.154	0.151	0.15	0.160
2	0.102	0.094	0.097	0.097	0.091	0.094	0.096
3	0.154	0.166	0.158	0.153	0.14	0.156	0.155
4	0.079	0.074	0.062	0.076	0.088	0.09	0.078
5	0.13	0.124	0.147	0.158	0.162	0.152	0.146
6	0.215	0.216	0.215	0.215	0.215	0.215	0.215
7	0.145	0.165	0.155	0.147	0.151	0.142	0.151

Conclusions (example 1)

Four groups of wells are defined:

1. production and injection volumes are more than the average ones (wells 1, 6);

2. the injection is more and the production is less (well 2);

3. injection – less and production – more (well 3, 5, 7);

4. injection and production rates are less than the average volumes (well 4)

The best wells are the wells from the third group as they produce more than the average volume of gas and simultaneously they inject less than the average volume. However it doesn’t mean that they can take over more gas. From the point of view of water cut it’s better to inject gas into other more problem wells to separate gas-water contact line to move it further. The first group wells are characterized by high production and injection rates. The fourth group wells may be supportable. Though they produce less gas but that doesn’t cause larger capacity of gas injection. Second group wells are the worst having the least production and the highest injection rates.

Conclusion

1. Proposed a problem of optimal injection and production volumes distribution for UGS wells. Optimality criteria :
- minimum watercut of well production,
- maximum gas-water contact remoteness from well bottoms Критериями

2. Main solution algorithms are worked out and asserted. Test results prove their working efficiency

3. The peculiarity of optimization for UGS operation processes is that they are based on association of hydrodynamic and optimization calculations. It provides valuable optimization for production conditions of wells ans the same time we escape multi version calculations.

4. Proposed models and algorithms enable to define better and worse wells and to provide some strategies to decrease risk of well watercut

Thanks a lot!

Пример 2 Целевая функция: F() - минимальное расстояние от ГВК до интервалов перфорации скважин, критерий: $F(q_{11},\dots,q_{WT}) \to \max$

В таблицах указаны значения $u_{wt}=q_{wt}/Q_t$ (относительные объемы нагнетания и отбора)

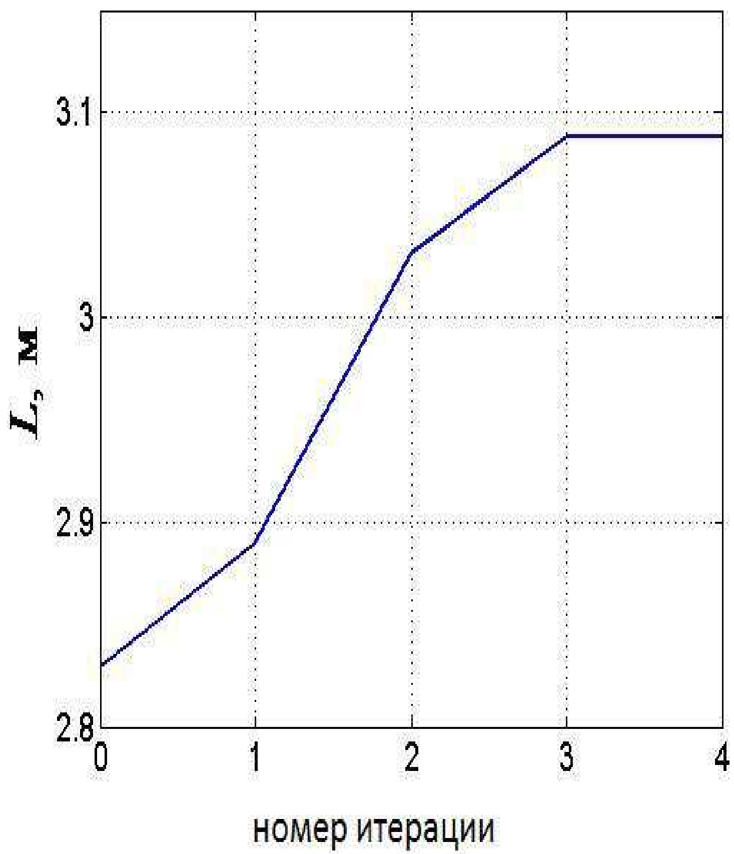
Оптимальные отн. объемы нагнетания по скважинам

№ скв. w	нагнетание						Ср. знач.
	№ периода, t						
	1	2	3	4	5	6	
1	0.157	0.135	0.125	0.114	0.1	0.097	0.121
2	0.191	0.189	0.195	0.197	0.194	0.198	0.194
3	0.168	0.19	0.206	0.206	0.208	0.205	0.197
4	0.217	0.217	0.218	0.218	0.218	0.201	0.215
5	0.066	0.058	0.051	0.059	0.055	0.076	0.061
6	0.107	0.119	0.121	0.109	0.126	0.135	0.120
7	0.094	0.092	0.084	0.096	0.1	0.088	0.092

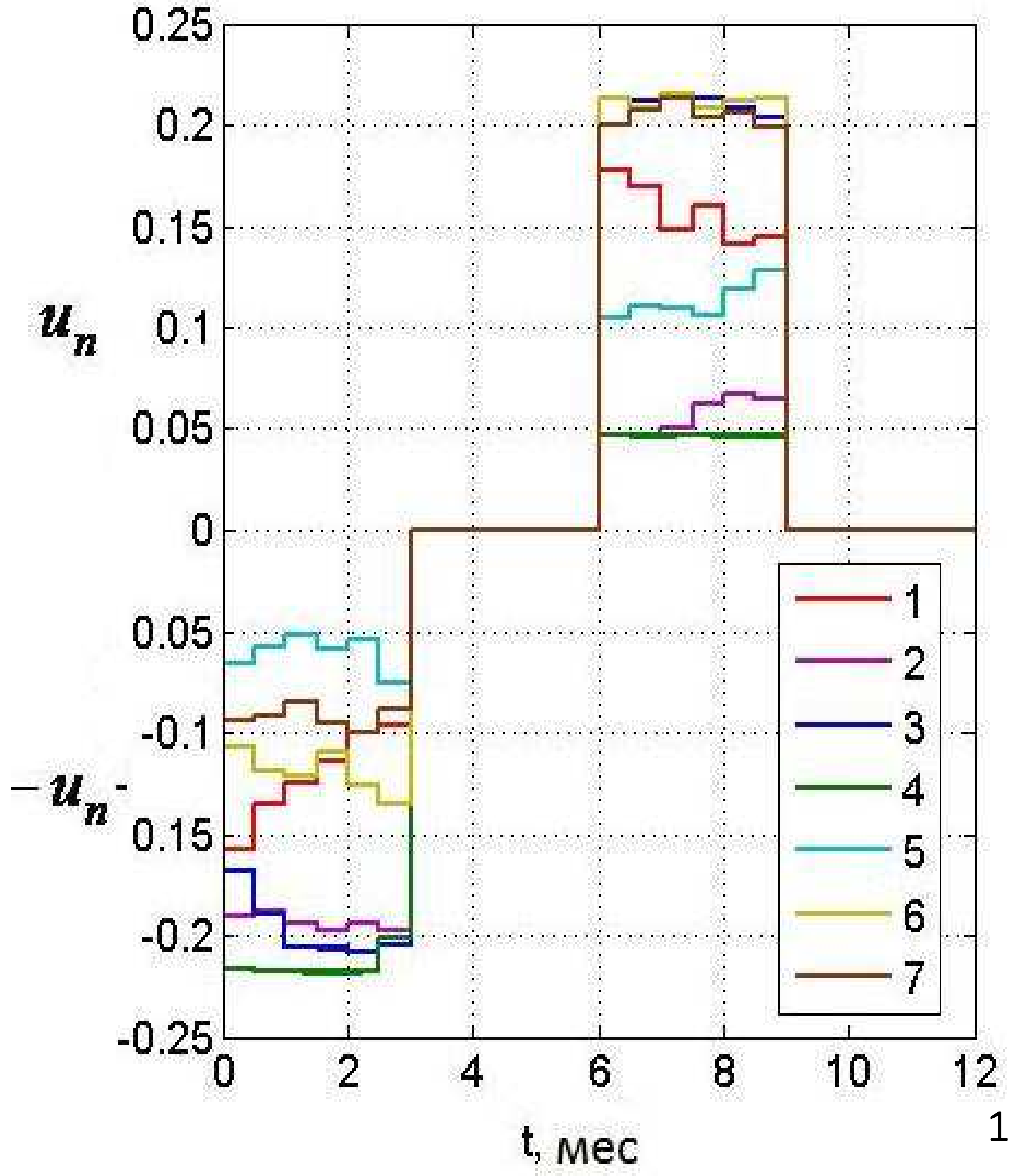
Оптимальные отн. объемы отбора по скважинам

№ скв. w	отбор						Ср. знач.
	№ периода, t						
	13	14	15	16	17	18	
1	0.177	0.169	0.149	0.16	0.141	0.144	0.157
2	0.047	0.047	0.05	0.062	0.068	0.065	0.057
3	0.213	0.212	0.215	0.213	0.208	0.203	0.211
4	0.047	0.047	0.047	0.047	0.047	0.047	0.047
5	0.105	0.111	0.11	0.106	0.119	0.129	0.113
6	0.213	0.209	0.215	0.209	0.212	0.213	0.212
7	0.199	0.207	0.213	0.204	0.206	0.199	0.205

Изменение целевой функции по итерациям (пример 2)



Оптимальные динамики нагнетания и отбора для скважин (пример 2)



Выводы (пример 2)

Выделяются 4 группы скважин, в которых:
1) нагнетание и отбор выше среднего (3);
2) нагнетание выше, а отбор ниже среднего (2,4);
3) нагнетание ниже, а отбор выше среднего (1,6,7);
4) нагнетание и отбор ниже среднего (5).

В четвертую группу попала скважина 5, которую следует считать «благополучную», т.к. в ней показатели отбора значительно превышают показатели нагнетания.

Во вторую группу попали вторая и четвертая скважины. Согласно результатам проведенного численного исследования в этих скважинах имеются наибольшие риски обводнения.