Coupling reservoir + production simulators

network
well

- porous media
- wellbore flow can be included with tubing tables
- transient

- flowline + pipeline + wellbore flow
- steady state ($\partial/\partial t = 0$)
- runs with IPR as boundary conditions on well

Example of explicit coupling strategy

Reservoir simulator

t_1, p_R^i, S_o^i, S_w^i, S_g^i, K_{rg}, K_{ro}

→ generated "IPR's"

Production simulator

Analytical model for IPR

$q_g = C_R\left(p_R^2 - p_{wf}^2\right)^n$

$q_o = J(p_R - p_{wf})$

$\frac{q_o}{q_{max}} = 1 - 0.2\frac{p_{wf}}{p_R} - 0.8\frac{p_{wf}^2}{p_R^2}$

$q_{t_{target}}^i$

network model (optimization)

- choke opening
- esp frequency
- gas lift rate

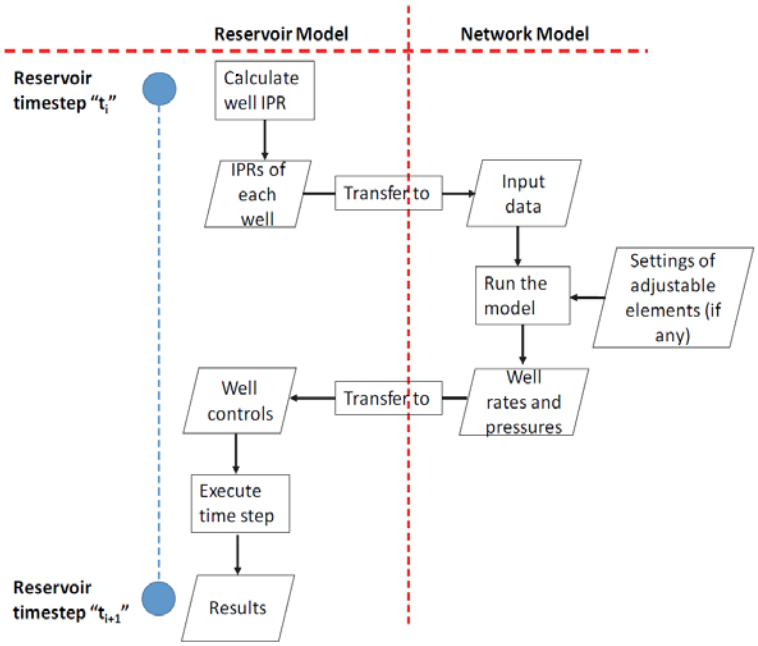
q_w^i, p_{wf}^i

compute

t_2, p_R, S_o, S_w, S_g, K_{rg}, K_{ro}

transfer IPR

and repeat...



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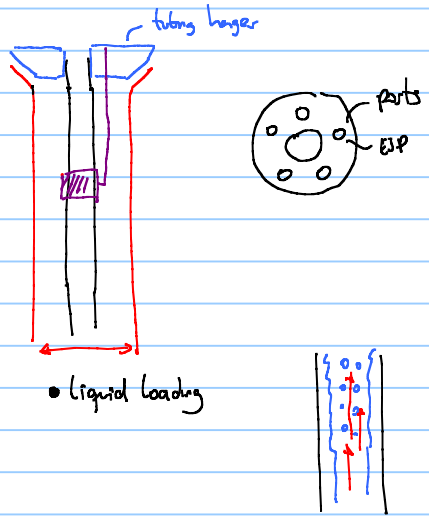
implicit coupling: requires either

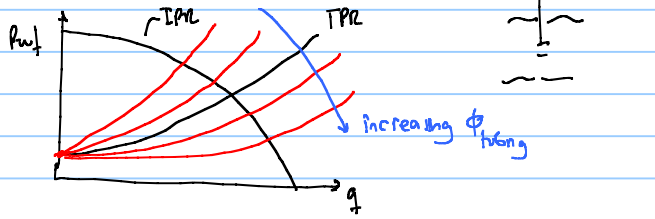
- solving all equations simultaneously
- re-run the step until some convergence is achieved

How to choose tubing size?

- maximize production
- reduce well costs
- fit the production casing 9 5/8"
- depends on tubing hager



for dry gas, bottomhole equilibrium



compare production gain against tubing cost

- liquid loading

$v_{sg} = \frac{q_g}{A}$ ← local rate of gas

$v_{sg} > v_{LL}$ → critical velocity

- erosional velocity

$v_{sg} < v_{erosional}$ → API 14E

In Norway

. DNV Recommended Practice RP O501)

(1) The velocity above which erosion may occur can be determined by the following empirical equation:

$$V_e = \frac{c}{\sqrt{pm}} \qquad \text{Eq. 2.14}$$

where:

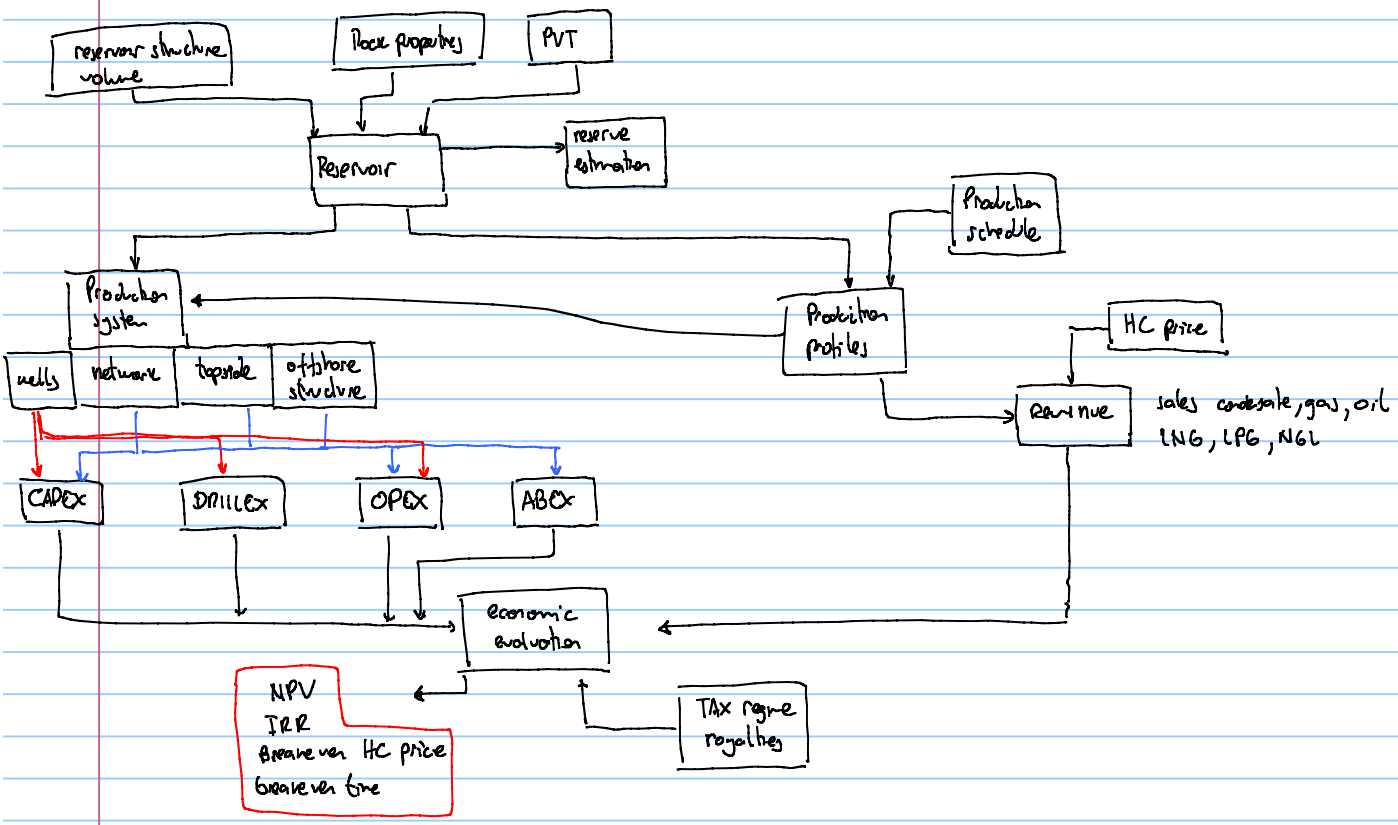
V_e = fluid erosional velocity, feet/second

c = empirical constant

pm = gas/liquid mixture density at flowing pressure and temperature, lbs/ft³

- to make decisions during Field development the company usually employs some economic indicator
  - NPV net present value (KPI) → TPG 5110 petroleum economics Trygve Strøm

Value chain model



CAPEX:
- engineering studies (salaries, consultants, contractor)
- processing facilities (separators, pumps, compressor, heat exchangers, control system, injection, export, water, oil, gas treatment)
- offshore structure (cost of platform, FPSO, TLP, living quarters, auxiliary equipment, power equipment)
- subsea system costs (template, flowline, pipeline, risers, umbilicals, control system, metering, boosting)
- export system

DRILLEX
- drilling rate of vessel
- drilling materials (tubulars, cement, mud, completion, wellhead)
- test during drilling (DST, logging, pressure test, sampling)
- X-mas tree
- drilling tools

OPEX
- Important to estimate abandonment rate.
- workers' salaries
- insurance
- maintenance
- equipment
- well intervention
- power consumption
- production chemicals (MEG, wax inhibitor, corrosion inhibitor, etc.)
- pigging
- transportation and export
- troubleshooting

ABEX
- well plugging
- removal of flowlines, pipelines, offshore structure
- cleaning
- monitoring

NPV calculations

$$NPV = \sum_{i=1}^{N} \frac{CF_i}{(1+d)^i}$$ ← abandonment

CF_i = revenue − expenditure at year "i"

↳ discount factor 5% → 12%

expenses are executed during early years so

$\frac{1}{(1+d)^i}$ is close to "1"

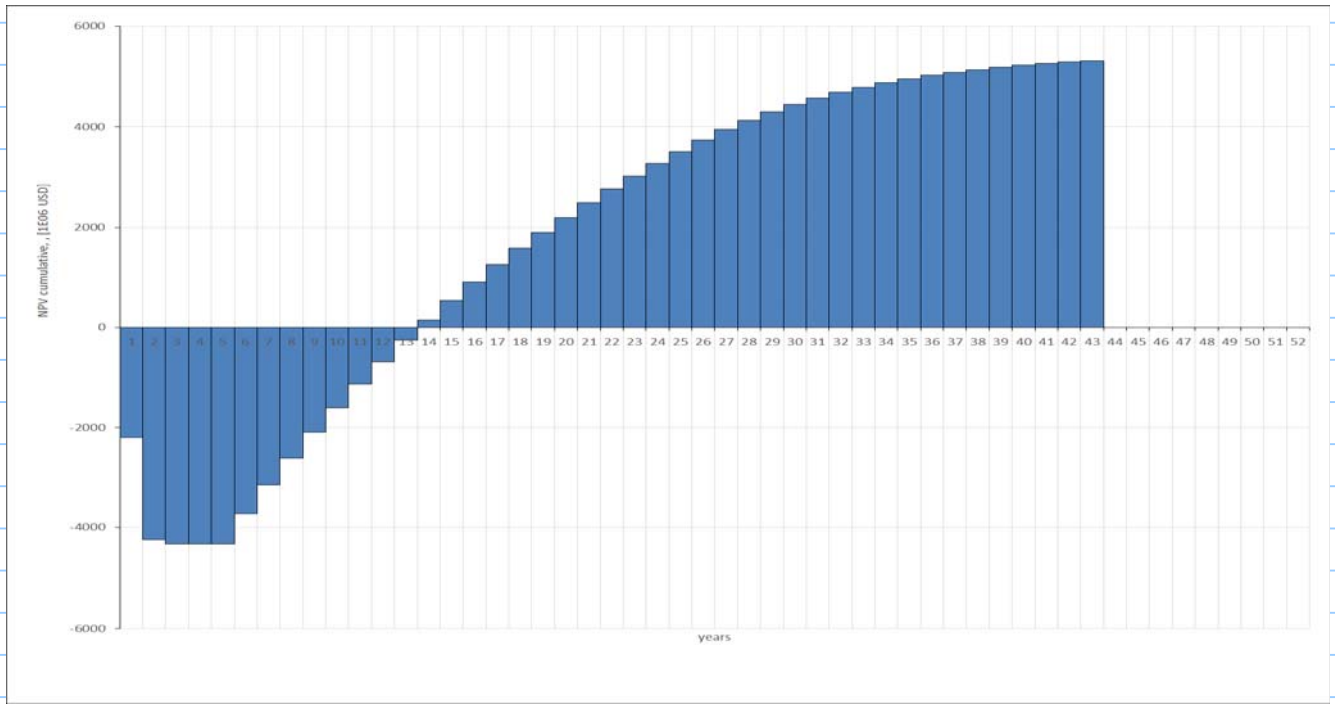
discount factor	0.07

year	1/(1+d)^i
1	0.934579
2	0.873439
3	0.816298
4	0.762895
5	0.712986
6	0.666342
7	0.62275
8	0.582009
9	0.543934
10	0.508349
11	0.475093
12	0.444012

Gas price	0.11	[usd/Sm^3]	
Discount rate	5	[%]	
LNG plant CAPEX	160	[usd/ Sm^3/d]	
well cost	1.00E+02	[1E06 USD]	(paid in years 1 and 2)
LNG carrier cost	2.00E+02	[1E06 USD]	(each carrier has a capacity of 145000 Sm3 LNG, or 86E06 Sm3 og gas, can do 22 trips in a year, amount paid evenly during the first two years)
Subsea manifold cost	2.00E+01	[1E06 USD]	
Pipeline and umbilicals	5.00E+02	[1E06 USD]	(paid in years 1 and 2)

	NPV [1E06 USD]	5316

	CAPEX									
End of year	DRILLEX	Subsea	LNG Plant	LNG vessels	TOTAL CAPEX	Yearly gas offtake	Revenues	Cash flow	Discounted cash flow	NPV
[-]	[1E06 USD]	[1E06 USD]	[1E06 USD]	[1E06 USD]	[1E06 USD]	[Sm^3]	[1E06 USD]	[1E06 USD]	[1E06 USD]	[1E06 USD]
1	400	310	1600		2310	0.00E+00	0	-2310	-2200	-2200
2	400	250	1600		2250	0.00E+00	0	-2250	-2041	-4241
3	100	0	0		100	0.00E+00	0	-100	-86	-4327
4	0	0	0		0	0.00E+00	0	0	0	-4327
5	0	0	0		0	0.00E+00	0	0	0	-4327
6	0	0	0		0	7.30E+09	803	803	599	-3728
7	0	0	0		0	7.30E+09	803	803	571	-3157
8	0	0	0		0	7.30E+09	803	803	544	-2614
9	0	0	0		0	7.30E+09	803	803	518	-2096
10	0	0	0		0	7.30E+09	803	803	493	-1603
11	0	0	0		0	7.30E+09	803	803	469	-1134
12	0	0	0		0	7.30E+09	803	803	447	-687
13	0	0	0		0	7.30E+09	803	803	426	-261
14	0	0	0		0	7.30E+09	803	803	406	145
15	0	0	0		0	7.30E+09	803	803	386	531
16	0	0	0		0	7.30E+09	803	803	368	899
17	0	0	0		0	7.30E+09	803	803	350	1249
18	0	0	0		0	7.30E+09	803	803	334	1583
19	0	0	0		0	7.30E+09	803	803	318	1901
20	0	0	0		0	7.30E+09	803	803	303	2203
21	0	0	0		0	7.30E+09	803	803	288	2492
22	0	0	0		0	7.30E+09	803	803	275	2766
23	0	0	0		0	7.30E+09	803	803	261	3028
24	0	0	0		0	7.30E+09	803	803	249	3277
25	0	0	0		0	7.30E+09	803	803	237	3514
26	0	0	0		0	7.30E+09	803	803	226	3740
27	0	0	0		0	7.15E+09	786	786	211	3950
28	0	0	0		0	6.64E+09	731	731	186	4136
29	0	0	0		0	6.17E+09	678	678	165	4301
30	0	0	0		0	5.72E+09	630	630	146	4447
31	0	0	0		0	5.31E+09	584	584	129	4576
32	0	0	0		0	4.92E+09	542	542	114	4689
33	0	0	0		0	4.56E+09	502	502	100	4790
34	0	0	0		0	4.22E+09	464	464	88	4878
35	0	0	0		0	3.90E+09	429	429	78	4956
36	0	0	0		0	3.60E+09	396	396	68	5024
37	0	0	0		0	3.32E+09	365	365	60	5084
38	0	0	0		0	3.06E+09	336	336	53	5137
39	0	0	0		0	2.81E+09	309	309	46	5183
40	0	0	0		0	2.58E+09	284	284	40	5224
41	0	0	0		0	2.36E+09	260	260	35	5259
42	0	0	0		0	2.16E+09	237	237	31	5289
43	0	0	0		0	1.97E+09	216	216	27	5316


6000
4000
2000
0
-2000
-4000
-6000
NPV cumulative, [1E06 USD]
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
years