## «Static» production optimization

### Prof. Milan Stanko (NTNU)



## Course material:

-http://www.ipt.ntnu.no/~stanko/files/Courses/PetCyb/2024/



## Agenda

- Introduction to production optimization
  - Practical meaning
  - Time scales
  - Model-based optimization
  - Types
- Example: two gas-lifted wells
- Exercise: two gas-lifted wells
- Discrete variables
  - Exercise: routing 5 wells to 2 separators
- How do solvers work?
- Multi-objective optimization
  - Constraint method
  - Linear scalarization
- Effect of uncertainties
- Proxy modeling using tables
  - Example: Gas-lifted well
- Proxy modeling using NN
  - Exercise in python
- Limitations and pitfalls of production optimization







### Examples of «production optimization»



 Detect locations in the system with abnormally high-pressure loss and flow restrictions



## Examples of «production optimization»



Verification of equipment design conditions vs actual operating conditions





### Examples of «production optimization»

- Identification and addressing fluid sources that have "disadvantageous" characteristics (e.g. high water cut, high H<sub>2</sub>S content)
- Identify and correct system malfunctions and unintended behavior
- Analyze and improve the logistics and planning of maintenance, replacement and installation of equipment or in the execution of field activities.









- Review the occurrence of failures and recognize patterns (data analytics)
- Calibration of instrumentation
- Identification of operational constraints (e.g. water handling capacity, power capacity)











- Identify bottlenecks
- Identifying and monitoring Key Performance Indicators (KPIs)







- Find:
  - Control settings of equipment
  - System characteristics (design)





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  - Give a production/profit higher than current
  - Give maximum production/profit possible
  - Improve a KPI
  - Maximize a KPI





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### Time scales of production optimization

	Long term	Short term	Shorter term
•	Years, months	Daily, weekly	<ul> <li>Seconds, minutes, hours</li> </ul>



#### **OPTIMIZATION TIMESCALES**





### Time scales of production optimization and models

Long term	Short term	Shorter term
Years, months	Daily, weekly	Seconds, minutes, hours
-Models are highly uncertain (limited data) -Models are typically transient (reservoir model) + steady-state models	<ul> <li>There is data to tune models</li> <li>Models are typically steady state (network, well, processing plant)</li> </ul>	-Transient/steady state -Model/real system



### Integrated asset modeling



### Model-based production optimization



# Ensuring fidelity in model-based production optimization





### Model-based production optimization workflow



### Time scales of production optimization and examples

Long term	Short term	Shorter term
-Find:	-Find: Choke opening,	-Find:
-well placement, well	gas lift rate, pump	-Control choke
rates, field development	frequency	opening, gas lift rate,
strategy	-That:	control valve position
-That:	-Maximize oil	-That:
-maximize recovery	production, condensate	-Maximize
factor, NPV, reduce	production, gas	production, revenue,
water cut and GOR	production, revenue	reduce and mitigate
		fluctuations



### **Optimization types**

- Parametric (static) using a model
- Dynamic (control) using a model, physical system, or a combination of both







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Milan



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Alexey



## Example: two gas-lifted wells



### System description



### System sketch (2 wells to one separator)



### Brute force solution



### Color map of total oil production versus gas lift

rates



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### Contour lines of total oil production





### Constraints in available gas



### Effect of constraints



### Maximizing profit instead of total oil production



### Maximizing profit instead of total oil production



# Exercise: optimization of two gaslifted wells


## Equation for gas lift performance curve



# **Discrete variables in production** optimization Exercise: well routing to separators



## System sketch





## Estimating number of combinations







## How do solvers work?



## **Optimization methods**

- Simplex (linear problems)
- Derivative-based (gradients, hessians)
- Line search/ Trust region
- Heuristic



 $x_k + \Delta x$  is a local extremum if:

$$\nabla f(x_k + \Delta x) = 0$$



https://jamesmccaffrey.wordpress.com/page/2/



#### Stanko (2019)



$$\nabla f(x_k + \Delta x) = 0$$

 $abla f(x_k) + H$  .  $\Delta x = 0$  (Taylor expansion)





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$$\nabla f(x_k + \Delta x) = 0$$

 $abla f(x_k) + H$  .  $\Delta x = 0$  (Taylor expansion)



$$\Delta x = -H^{-1}.\nabla f(x_k)$$

 $x_{k+1} = x_k + \Delta x$ 



https://jamesmccaffrey.wordpress.com/page/2/

#### Taken from Arnand Noffmann

#### Stanko (2019)



Stanko (2019)

#### demonstrations.wolfram.com/MinimizingTheRosenbrock

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# Estimation of gradient – analytical estimation



# Estimation of gradient – perturbation method



## Pattern search



Stanko (2019)

https://en.wikipedia.org/wiki/Pattern\_search\_(oj

#### 



## Evolutionary algorithms (e.g. GA)



## **Multi-objective production optimization**



## DEFINITION

- More than one optimization objective (KPI), e.g.
  - Oil, condensate or gas production
  - NPV
  - Equipment efficiency
  - Energy consumption
  - Downtime
  - Maintenance cost
  - OPEX
  - CAPEX
  - CO<sub>2</sub> emissions



### COMPLEXITIES

- Techniques are usually developed for optimizing one objective
  - When an objective is optimal usually all rest are not
  - $\rightarrow$  How to combine all objectives into one?



### COMPLEXITIES

- Techniques are usually developed for optimizing one objective
  - When an objective is optimal usually all rest are not
  - $\rightarrow$  How to combine all objectives into one?
- Conflicting (non-trivial) objectives
  - High revenue  $\rightarrow$  more energy usage
  - High rates  $\rightarrow$  more equipment failure
  - High production  $\rightarrow$  more CO<sub>2</sub> emissions



#### **APPROACHES – CONSTRAINT METHOD**

- Set most important KPI as objective
- Set the rest as constraints.
- Define an acceptable level for the constraints
- Run the optimization and evaluate results, adjust levels as necessary

$$egin{array}{lll} \min & f_j(x) \ {
m s.t.} & x\in X \ & f_i(x)\leq \epsilon_i ext{ for } i\in\{1,\ldots,k\}\setminus\{j\}, \end{array}$$



#### **APPROACHES – LINEAR SCALARIZATION**

- Normalize the KPIs with reference values
- Create an objective function that is the weighted sum of all KPIs

$$\min_{x\in X}\sum_{i=1}^k w_i f_i(x)$$

• Run the optimization and evaluate results, adjust weights as necessary



#### **APPROACHES – LINEAR SCALARIZATION**

- Normalize the KPIs with reference values
- Create an objective function that is the weighted sum of all KPIs

$$\min_{x\in X}\sum_{i=1}^k w_i f_i(x)$$

Be careful with the signs!, squaring might be needed, changing the sign or inversion

• Run the optimization and evaluate results, adjust weights as necessary



max

$$f(x) = w \cdot f_1(x) + (1 - w) \cdot f_2(x)$$













max

$$f(x) = w \cdot f_1(x) + (1 - w) \cdot f_2(x)$$





**PARETO FRONT** 









## **Effect of uncertainties**





## Proxy modeling



# Proxy models Interpolation on tables



## Principle



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## Principle



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0.0031515


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1	100	89	11	0.0623	2959.83	200	41.7848	41.7848	0.076605	2/59.75	0.46442	133,296	1.45366	0.0031515
2	130.176	115.857	14.3194	0.0811	2813.43	200	42.3244	42.3244	0.12223	2613.31	0.6657	136.956	1.94428	0.0037617
3	169.458	150.818	18.6404	0.10557	2598.22	200	43.0246	43.0246	0.21882	2398	0.87479	137.603	2.54295	0.0046161
4	220.594	196.329	24.2653	0.13743	2338.12	200	43.9348	43.9348	0.41829	2137.7	1.14017	137.687	3.31234	0.0057147
5	287.16	255.573	31.5876	0.1789	2111.14	200	45.118	45.118	0.74225	1910.39	1.487	137.816	4.3159	0.0071794
6	373.814	332.694	41.1195	0.23289	1891.68	200	46.6559	46.6559	1.26334	1690.4	1.94014	137.973	5.62468	0.0090713
7	486.616	433.089	53.5278	0.30316	1714.93	200	48.6555	48.6555	2.09277	1512.82	2.53426	138.21	7.33453	0.011634
8	633.458	563.778	69.6804	0.39464	1588.75	200	51.2558	51.2558	3.39182	1385.32	3.31512	138.547	9.57111	0.015113
9	824.611	733.903	90.7072	0.51373	1534.78	200	54.6373	54.6373	5.39024	1329.33	4.3445	139.012	12.5011	0.019751
10	1073.45	955.367	118.079	0.66876	1532.18	200	59.032	59.032	8.49909	1323.59	5.70645	139.637	16.3466	0.026098
11	1397.37	1243.66	153.711	0.87056	1533.9	200	64.7255	64.7255	13.4182	1320.31	7.51604	140.458	21.4044	0.034887
12	1819.04	1618.95	200.094	1.13326	1541.85	200	72.0202	72.0202	21.1962	1320.36	9.93086	141.507	28.0716	0.047581
13	2367.95	2107.48	260.475	1.47524	1559.84	200	81.1299	81.1299	33.4509	1325.88	13.1638	142.794	36.8749	0.066011
14	3082.51	2743.43	339.076	1.9204	1588.34	200	92.0322	92.0322	52.8814	1334.55	17.4946	144.28	48.5018	0.093597
15	4012.69	3571.29	441.396	2.49991	1646.14	200	104.382	104.382	83.1839	1361.37	23.2783	145.869	63.8332	0.13534
16	5223.56	4648.97	574.592	3.25428	1737.99	200	117.559	117.559	130.416	1404.8	30.9437	147.404	83.9698	0.20003
17	6799.83	6051.85	747.981	4.23629	1876.24	200	130.83	130.83	202.509	1468.89	40.9987	148.711	110.278	0.30158
18	8851.75	7878.06	973.692	5.51464	2081.02	200	143.52	143.52	312.051	1560.59	54.0072	149.595	144.409	0.46246
19	11522.9	10255.3	1267.51	7.17874	2372.74	200	155.127	155.127	473.577	1684.9	70.5062	149.81	188.255	0.72122
20	15000	13350	1650	9.345	2771.01	200	165.36	165.36	705.925	1841.21	90.825	149.027	243.782	1



MODEL

### Principle







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**PROSPER MODEL** 





VLP (TUBING (	VLP (TUBING CURVE) CALCULATIONS (Well1A.out) (Matched PVT)																					
Done Can	cel Cage	s C <u>a</u> lculate	Plot	Export	: Lift Curve	<u>Export</u>	Help		<u>G</u> enerat	e <u>S</u> ave F	tesults	<u>T</u> ransfer Data	GAP									
Top N	ode Pressure Water Cut Total GOR	0	psig percent scf/STB		Point	Liquid Rate	Oil Rate	Water Rate	Gas Rate	VLP Pressure	WellHead Pressure	WellHead Temperature	First Node Temperature	dP Friction	dP Gravity	Total NoSlip Velocity	Erosional Velocity	C Factor	Maximum Grain Diameter	Erosion Rate	Corrosion Rate	Erosional Velocity Flag
Surface Equipmer	nt Correlation	Beggs and Brill				(STB/day)	(STB/day)	(STB/day)	(MMscf/day)	(psig)	(psig)	(deg F)	(deg F)	(psi)	(psi)	(ft/sec)	(ft/sec)		(inches)	(0.001	(0.001	
Vertical Li	ft Correlation	Petroleum Experts 2	1.03 1.01		1	100	100	0	0.07	2813.29	200	41.6084	41.6084	0.086236	2613.21	0.56482	144.43	1.56426	0.0032735			No
	Rate Method	User Selected			2	130.176	130.176	0	0.091123	2613.88	200	42.0942	42.0942	0.14071	2413.74	0.73791	144.691	2.03997	0.0038838			No
	Rate Type	Liquid Rate				160.459	160.459	0	0 11960	2200 72	200	42 7244	40 7044	0.25104	2100.47	0.06793	145.025	2 66554	0.0047292			No
	First Node	1 Xmas Tree 600 (fe	et)		-	109.430	109.430	0	0.11002	2390.72	200	72.7277	72.7277	0.23104	2190.47	0.90782	145.255	2.00334	0.0047382			NO
Techudo Sand Cont	Last Node	8 Casing 9275 (feet, No	)		4	220.594	220.594	0	0.15442	2093	200	43.5436	43.5436	0.48479	1892.51	1.26117	145.31	3.47168	0.0059588			No
PE5	Stability Flag	No			5	287.16	287.16	0	0.20101	1842.9	200	44.6084	44.6084	0.85156	1642.04	1.64448	145.431	4.52305	0.0074235			No
Enter Rates					6	373.814	373.814	0	0.26167	1654.36	200	45.9926	45.9926	1.42577	1452.92	2.14494	145.574	5.89374	0.0094985			No
Point		Liquid Rate		^	7	486.616	486.616	0	0.34063	1501.13	200	47.792	47.792	2.32833	1298.79	2.80059	145.793	7.68376	0.012184			No
Point		(STB/day)		_	8	633.458	633.458	0	0.44342	1399.08	200	50.1319	50.1319	3.7293	1195.31	3.66152	146.109	10.0241	0.015907			No
1	100			_		824 611	824 611	0	0 57723	1396-36	200	53 1749	53 1749	5 83527	1100.46	4 70514	146 549	13 0992	0.020728			No
2	130.176			_		024.011	024.011	-	0.37723	1390.30	200	55.1746	55.1746	5.65527	1150.40	4.75514	1-0.5-0	15.0002	0.020720			
4	220.594				10	1073.45	1073.45	U	0.75141	1401.02	200	57.1311	57.1311	9.15553	1191.75	6.2929	147.143	17.1069	0.02/319			No
5	287.16				11	1397.37	1397.37	0	0.97816	1410.05	200	62.266	62.266	14.3799	1195.48	8.27971	147.93	22.3882	0.036534			No
6	373.814				12	1819.04	1819.04	0	1.27333	1424.77	200	68.8836	68.8836	22.606	1201.83	10.9267	148.946	29.3442	0.049778			No
7	486.616				13	2367.95	2367.95	0	1.65757	1441.26	200	77.2505	77.2505	35.5421	1205.13	14.4667	150.211	38.5236	0.069185			No
8	633.458				14	3082.51	3082 51	0	2 15776	1481.55	200	87 4555	87 4555	55 9552	1224 57	19 2082	151 703	50 6467	0.097991			No
9	824.611			_																		
10	1073.45			_	15	4012.69	4012.69	0	2.80888	1543.05	200	99.2851	99.2851	87.7619	1253.49	25.5467	153.339	66.6409	0.14169			No
11	1819.04			_	16	5223.56	5223.56	0	3.65649	1638.02	200	112.216	112.216	137.195	1297.68	33.9674	154.972	87.6739	0.20906			No
13	2367.95			~	17	6799.83	6799.83	0	4.75988	1781.71	200	125.537	125.537	213.179	1363.03	45.0327	156.394	115.178	0.31355			No
		2 10 1000	- >	_	18	8851.75	8851.75	0	6.19622	1991.74	200	138.531	138.531	327.076	1455.15	59.3583	157.373	150.873	0.47759			No
t - (Top	Node Pressu	e=200) (Gas Oil Rat	io=700) (Wa	ater Cui	10	11522.0	11522.0	0	9.066	2201.40	200	150 619	150 619	402 291	1591 90	77 5210	157 620	106 72	0 72921			No
2 - (Top	Node Pressu	e=200) (Gas Oil Rat	io=700) (Wa	ater Cu	19	11322.9	11322.9	•	0.000	2231.73	200	130.019	130.019	193.301	1301.09	77.5219	137.029	190.72	0.73031			
e 3-(lop	Node Pressu Node Pressu	e=200) (Gas Oil Rat e=200) (Gas Oil Rat	io=700) (Wa io=700) (Wa	ater Cul	20	15000	15000	0	10.5	2706.2	200	161.425	161.425	734.369	1744.69	99.8259	156.776	254.696	1			No
5 - (Top	1 a	2550																				
< 6 - (Top	Node Pressu	e=200) (Gas Oil Rat	10=700) (Wa	ater Cur ∨	- c	Case 1 (Top No	de Pressure=	200) (Gas Oil R	atio=700) (Wat	er Cut=0)												

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SELECT VARIABLES (Well1A.out)			_	×
Done Cancel Main Help	Reset All Combinati	ions		
Variables	Variable Data			
		Top Node Pressure		
Cas Oil Patio	psig	Reset		
3 Water Out	1 200	Generate		
4	2 622.222	Clear Data		
5	3 1044.44			
6	4 1466.67			
7	5 1888.89			
8	6 2311.11			
9	7 2733.33			
10 🔽	8 3155.56			
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	11			
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Ore         Cape         Cape         Cape         Convert         Spec Hour         Tourier Date         Cape           Toy Unde Pressor         Odd         orm	<b>VLP (TUBING </b>	CURVE) CALCULATIONS (Well1A.out) (Mate	ched PVT)																		
Tote of ensure 20         point         point         point         point         print take	Done Can	cel Cages Calculate Plot	Export	t Lift Curv	e <u>E</u> xport	t <u>H</u> elp	]	Generat	e <u>S</u> avel	Results	Transfer Data	GAP									
Improvement         Improvement     <	Ten N	ada Brassura 200			Liquid Pate	Ol Pate	Water Date	Gac Pate	VI P Pressure	WellHead	WallHard	First Node	dP Eriction	dP Gravity	Total NoSlin	Erosional	CEaster	Maximum	Erocion Data	Corrotion	Erocional
Link Colubit         Link Colubit<	TOP N	Water Cat 0			ciquid Kate	Oil Rate	water Rate	Gas Kate	VEP Pressure	Pressure	Temperature	Temperature	dir Theadh	ur dravity	Velocity	Velocity	Cractor	Grain	LI OSIOIT KALE	Rate	Velocity Flag
Diracial Construction	L	Table con and active active		Point														Diameter			
No           No </td <td>Surface Equipmor</td> <td>t Correlation Room and Prill</td> <td></td> <td></td> <td>(STB/day)</td> <td>(STB/dav)</td> <td>(STB/dav)</td> <td>(MMscf/dav)</td> <td>(psig)</td> <td>(psig)</td> <td>(deg F)</td> <td>(dea F)</td> <td>(psi)</td> <td>(psi)</td> <td>(ft/sec)</td> <td>(ft/sec)</td> <td></td> <td>(inches)</td> <td>(0.001</td> <td>(0.001</td> <td></td>	Surface Equipmor	t Correlation Room and Prill			(STB/day)	(STB/dav)	(STB/dav)	(MMscf/dav)	(psig)	(psig)	(deg F)	(dea F)	(psi)	(psi)	(ft/sec)	(ft/sec)		(inches)	(0.001	(0.001	
Normal Set Method for Society 1         No	Vertical Li	ft Correlation Petroleum Experts 2 1 03 1 01		1	100	100	0	0.07	2813.20	200	41 6084	41 6084	0.086236	2613.21	0 56492	144 43	1 56426	0.0032735			No
Note free         Output Date	Ter dear er	Rate Method User Selected		-	100	100		0.07	2013.23	200	11.0001	41.0004	0.000230	2013.21	0.30%2	111.15	1.30420	0.0032733			
Piret total         Jose of the decomp 2017 (ref.)         Jose decomp 2017 (ref.) <td>L</td> <td>Rate Type Liquid Rate</td> <td></td> <td>2</td> <td>130.176</td> <td>130.176</td> <td>0</td> <td>0.091123</td> <td>2613.88</td> <td>200</td> <td>42.0942</td> <td>42.0942</td> <td>0.14071</td> <td>2413.74</td> <td>0.73791</td> <td>144.691</td> <td>2.03997</td> <td>0.0038838</td> <td></td> <td></td> <td>No</td>	L	Rate Type Liquid Rate		2	130.176	130.176	0	0.091123	2613.88	200	42.0942	42.0942	0.14071	2413.74	0.73791	144.691	2.03997	0.0038838			No
Last No.         Camp 9278 (Net)         Image: Camp 9278 (Net)         Imag		First Node 1 Xmas Tree 600 (feet)		3	169.458	169.458	0	0.11862	2390.72	200	42.7244	42.7244	0.25104	2190.47	0.96782	145.235	2.66554	0.0047382			No
b       b		Last Node 8 Casing 9275 (feet)		4	220.594	220,594	0	0.15442	2093	200	43,5436	43,5436	0.48479	1892.51	1.26117	145.31	3,47168	0.0059588			No
PES Stability Flig         No         0.71         0.7         0.71         0.72         0.70         0.72         7.7         0.72         7.72	Include Sand Cont	rol Pressur No																			
Perty         Ligad Rate (57)(dsy)         0         23.84         73.84         9         0.56.67         165.95         45.995         1.4257         142.92         2.1499         145.75         5.000906         0.004985         0.004985         0.004985         0.004985         0.004985         0.004985         0.004985         0.004985         0.00185         0.00185	PES	Stability Flag No		5	287.16	287.16	U	0.20101	1842.9	200	44.6084	44.6084	0.85156	1642.04	1.64448	145.431	4.52305	0.0074235			NO
Period         Usadd Rate         7         66.66         66.66         0         0.9463         150.1         0         7.837         7.837         0.2124         0.1507         0         0           2         10.1         10         0         0         0.133         0.1313         0.1313         0.1313         0.1313         0.1313         0.1313         0.1313         0.1313         0.1133	Enter kates			6	373.814	373.814	0	0.26167	1654.36	200	45.9926	45.9926	1.42577	1452.92	2.14494	145.574	5.89374	0.0094985			No
Frank         (STB(day))         (STB(day)) </td <td>Deint</td> <td>Liquid Rate</td> <td>^</td> <td>7</td> <td>486.616</td> <td>486.616</td> <td>0</td> <td>0.34063</td> <td>1501.13</td> <td>200</td> <td>47.792</td> <td>47.792</td> <td>2.32833</td> <td>1298.79</td> <td>2.80059</td> <td>145.793</td> <td>7.68376</td> <td>0.012184</td> <td></td> <td></td> <td>No</td>	Deint	Liquid Rate	^	7	486.616	486.616	0	0.34063	1501.13	200	47.792	47.792	2.32833	1298.79	2.80059	145.793	7.68376	0.012184			No
1         100         00-40         0         0-40         0-40<	Point	(STB/day)			622.459	622.459	0	0 44747	1200.09	200	50 1210	50 1210	2 7202	1105 21	2 66152	146 100	10.0241	0.015907			No
2       10.1/6       9       82.4.6.1       62.4.6.1       0       5.773       136.35       200       5.1748       5.31748       5.3322       1190.4       4.7514       146.548       13.0822       0.00728       0       No         4       220.594       10       107.45       07.45       0       0.7514       140.02       200       5.1178       5.1311       9.1553       1191.75       6.229       147.143       17.169       0.02728       0       No         5       287.16       10       107.45       07.345       0       0.75141       140.02       200       62.266       14.379       1195.48       8.2771       147.43       20.36534       0.069185       0.069185       0       No         7       496.616       373.314       139.75       128.179       141.26       200.75       77.2505       35.5421       120.13       14.967       150.211       35.276       0.069185       0.069185       No       No         10       1073.45       010.317.45       020.2157       141.26       200.75       77.2505       55.9552       122.457       150.211       35.2470       0.097991       No       No         11       1397.37       020.25	1	100		°	033.430	655.456	0	0.44542	1399.00	200	50.1519	50.1519	3.7293	1195.51	3.00132	140.109	10.0241	0.013907			NO
3       169-483       200.594       7.013.4       9.07.45       9.111       9.07.45       9.07.314       9.17.31       9.1553       191.75       6.292       17.43       7.140       0.02719       0       No         5       202.594       202.594       20.354       191.75       6.292       17.43       17.099       0.02719       0       No         6       37.361       207.56       20.56       22.66       2.266       2.266       10.133       109.57       149.49       0.93534       0.09534       0       No         7       466.16       37.364       10       107.345       267.95       267.95       141.25       20       7.2895       7.2895       5.552       12.45       15.03       6.6499       0.04978       0 </td <td>2</td> <td>130.176</td> <td></td> <td>9</td> <td>824.611</td> <td>824.611</td> <td>0</td> <td>0.57723</td> <td>1396.36</td> <td>200</td> <td>53.1748</td> <td>53.1748</td> <td>5.83527</td> <td>1190.46</td> <td>4.79514</td> <td>146.548</td> <td>13.0882</td> <td>0.020728</td> <td></td> <td></td> <td>No</td>	2	130.176		9	824.611	824.611	0	0.57723	1396.36	200	53.1748	53.1748	5.83527	1190.46	4.79514	146.548	13.0882	0.020728			No
4       20.594       20.594       11       1397.37       1397.37       1397.37       197.37       141.05       20       6.266       14.379       195.48       8.771       147.93       2.382       0.36534       0       No         6       373.814       11       1397.37       1397.37       1397.37       141.65       200       6.8836       6.8836       2.666       131.83       10.927.1       145.467       50.417       0       No         10       1073.45       0       102.51       382.51       0       2.5776       141.55       200       7.455       5.5552       124.57       19.082       151.33       6.6499       0.1469       No         11       1397.37       1397.37       0       0.65649       138.02       20       7.455       5.5552       124.57       15.339       6.649       0.1469       No         12       1319.04       13       2367.95       5223.56       0       3.65649       138.02       20       112.216       137.19       126.339       126.537       127.37       126.308       154.97       157.33       6.649       0.1469       No         10       107.45       523.56       5223.56       0	3	169.458		10	1073.45	1073.45	0	0.75141	1401.02	200	57.1311	57.1311	9.15553	1191.75	6.2929	147.143	17.1069	0.027319			No
5       227.16       1.07.37       1.07.37       1.07.33       1.424.77       200       68.836       22.606       120.183       10.9267       148.946       29.3442       0.049778       No         6       373.814       12       189.94       189.97       1.424.77       200       68.836       62.606       120.183       10.9267       148.946       29.3442       0.049778       No       No         9       62.661       10       107.345       149.94       109.251       18.576       144.126       200       77.2505       55.952       122.457       19.2082       151.703       50.6467       0.09991       No         10       107.345       017.345       012.69       012.69       2.1576       148.155       200       87.4555       57.4552       122.457       19.2082       151.703       50.6467       0.09991       No         11       1397.37       010.33       042.651       3082.51       3082.51       02.8088       154.105       200       9.2851       97.250       15.395       15.393       66.6409       0.14169       No         12       139.94       25.957       14       3082.51       306.547       149.382       12.216       112.216	4	220.594		11	1207 27	1207 27	0	0.07916	1410.05	200	62.266	62.266	14 2700	1105.49	9 27071	147.02	22.2002	0.026524			No
6       37.3.814       12       1819.04       1919.04       1.27333       1424.77       200       68.885       22.606       121.83       10.927       149.496       29.342       0.049778       0       No         7       466.616       33.483       13       2367.95       2567.95       0       1.65757       141.25       00       77.2505       35.5421       120.51.3       14.4667       150.211       35.526       0.069185       0.097991       No       No         10       1073.45       0       017.345       0       2.0569       12.3576       154.30       0.04       9.2551       87.459       152.49       151.303       0.66409       0.097991       No       No         11       1397.37       139.04       0.01       2.23.56       52.3.56       0       3.65649       163.02       20       12.537       12.537       12.537       12.537       12.53.99       25.647       153.399       6.6409       0.14169       No       No         12       1519.04       522.356       523.56       0       3.65649       163.02       12.537       12.537       12.537       13.53.03       6.6409       15.178       0.3385       15.778       0.0906       <	5	287.16			1357.37	1397.37	•	0.57510	1410.05	200	02.200	02.200	14.3733	1155.46	0.2/3/1	147.55	22.3002	0.030334			
7       486.616       533.458       0.69185       0.69185       0.69185       0.69185         9       824.611       0.073.45       0.073.45       0.82.51       0.82.51       0.80195       0.80195       0.69185       0.61815       0.618	6	373.814		12	1819.04	1819.04	0	1.27333	1424.77	200	68.8836	68.8836	22.606	1201.83	10.9267	148.946	29.3442	0.049778			No
8       633.439       633.439       11       362.51       0       2.15776       148.155       200       87.4555       55.952       124.57       19.2082       151.703       50.6677       0.097991       0       No         10       1073.45       102.33       50.467       0.14169       0       2.08088       1543.05       200       92.851       97.851       87.659       153.39       66.649       0.14169       0       No         12       139.0.4       2367.95       236.795       5223.56       5223.56       0       3.65649       163.02       200       12.216       13.19       1237.46       15.473       56.967       15.979       0.2006       0       No         1       1397.37       2367.95       5223.56       0       3.65649       163.02       200       12.216       13.19       1363.03       45.027       15.939       0.6649       0.1469       No         2.700 Node Pressure=200 (Gas Ol Rato-700 (Water Cut-3)       15.738       65.952       12.537       13.19       136.313       157.373       150.873       0.47759       No       No         3.700 Node Pressure=200 (Gas Ol Rato-700 (Water Cut-3)       11       1522.9       152.9       0       0.562 </td <td>7</td> <td>486.616</td> <td>_</td> <td>13</td> <td>2367.95</td> <td>2367.95</td> <td>0</td> <td>1.65757</td> <td>1441.26</td> <td>200</td> <td>77.2505</td> <td>77.2505</td> <td>35.5421</td> <td>1205.13</td> <td>14.4667</td> <td>150.211</td> <td>38.5236</td> <td>0.069185</td> <td></td> <td></td> <td>No</td>	7	486.616	_	13	2367.95	2367.95	0	1.65757	1441.26	200	77.2505	77.2505	35.5421	1205.13	14.4667	150.211	38.5236	0.069185			No
9       824.611       1073.45       1074.45       <	8	633.458	_	14	3082.51	3082.51	0	2,15776	1481.55	200	87.4555	87.4555	55,9552	1224.57	19,2082	151,703	50.6467	0.097991			No
10       107.345       107.345       107.45	9	824.611	_		5002.51	5002.51		2.13770	1 101.00	200	07.1000	07.1000	55.5552	122 1.37	13.2002	151.705	50.0107				
11       1397.37         12       1819.04       523.56       523.56       0       3.6649       1638.02       200       112.216       137.195       1297.68       33.9674       154.972       87.6739       0.20966       No         13       2367.95       232.67.95       7       6799.83       6799.83       0       4.75988       1781.71       200       125.537       125.537       121.179       196.303       45.0327       156.394       115.178       0.31355       0       No         1       (10p Mode Pressure=200) (Gas OI Rabo=700) (Water Cut=1)       3       1152.29       191.74       200       136.51       32.7076       145.15       9.3833       157.373       150.873       0.7799       0       No         1       10p Mode Pressure=2000 (Gas OI Rabo=700) (Water Cut=1)       3       1152.29       10       6.066       291.49       200       150.619       493.381       151.89       7.5219       157.629       196.72       0.7831       No         3       -(Top Mode Pressure=200) (Gas OI Rabo=700) (Water Cut=3)       150.00       150.00       0.05       20.02       161.425       161.425       74.369       174.69       98.825       156.776       156.466       1.0       No	10	1073.45	_	15	4012.69	4012.69	0	2.80888	1543.05	200	99.2851	99.2851	87.7619	1253.49	25.5467	153.339	66.6409	0.14169			No
12       1819-04       13       2367.95       15       76       799.83       6799.83       6799.83       0       4.75988       1781.71       200       125.537       125.537       125.537       156.394       115.178       0.31355       No         1-(rop Mode Pressure=200) (Gas OI Ratio=700) (Water Cut=1)       1       152.9       152.9       1781.71       200       138.531       138.531       27.076       1455.15       95.383       157.373       150.873       0.47759       No         10       105000 (Pressure=200) (Gas OI Ratio=700) (Water Cut=2)       11522.9       11522.9       0       8.066       291.49       200       150.619       493.381       1581.89       77.5219       157.629       196.72       0.73831       No         5 - (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=3)       0       0       10.5       206.2       200       161.425       161.425       734.369       1581.89       77.5219       156.776       254.696       1       No         5 - (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=45)       10.500       0       10.5       206.20       161.425       161.425       734.369       156.776       254.696       1       No       No         5 - (Top Node Pressure=200) (Gas OI Ra	11	1397.37	_	16	5223.56	5223.56	0	3.65649	1638.02	200	112.216	112.216	137.195	1297.68	33.9674	154.972	87.6739	0.20906			No
13       2267.95       10       6797.63       0       47.956       16.171       200       125.37       213.179       156.02       165.02       156.174       156.03       450.327       156.174       156.174       156.174       156.03       450.327       156.174       156.175       156.175       156.174       156.175       156.174       150.874       156.175       156.175       156.175       156.175       156.174       150.874       156.175       156.175       156.175       156.174       150.874       156.174       150.874       156.175       156.175       157.833       157.737       150.875       0.47759       No         2.100 Node Pressure=2000 (Gas O Ratom-200) (Water Cut=10)       150.00       0       150.2706.2       200       151.425       151.425       151.425       156.19       156.19       156.19       156.19       156.19       156.19       156.19       156.19       156.19       156.19	12	1819.04		17	6700.02	6700.93	0	4 75099	1701 71	200	105 597	105 527	212.170	1262.02	45.0337	156 204	115 170	0.21255			No
1- (top Node Pressure=200) (clas OI Rato=700) (Water Cut=2)       18       8851.75       8851.75       0       6.19622       1991.74       200       138.531       327.076       1455.15       99.383       157.373       150.873       0.47759       No         2. (Top Node Pressure=200) (Clas OI Rato=700) (Water Cut=1)       19       11522.9       11522.9       0       8.066       2291.49       200       150.619       493.381       1581.89       77.5219       157.629       196.72       0.7831       No         3. (Top Node Pressure=200) (Glas OI Rato=700) (Water Cut=3)       5       15000       0       10.5       2706.2       200       161.425       734.369       174.69       99.8259       156.776       254.696       1       No         5       (Top Node Pressure=200) (Glas OI Rato=700) (Water Cut=4)       5       5       10.5       2706.2       200       161.425       734.369       174.69       99.8259       156.776       254.696       1       No         6       (Top Node Pressure=200) (Glas OI Rato=700) (Water Cut=4)       5       5       150.700       157.57       157.672       156.776       146.49       16       No         7       (Top Node Pressure=200) (Glas OI Rato=700) (Water Cut=5)       5       5       150.776 <td>13</td> <td>2367.95</td> <td>· ·</td> <td></td> <td>0733.03</td> <td>0799.00</td> <td>•</td> <td>4.73300</td> <td>1/01./1</td> <td>200</td> <td>125.557</td> <td>125.557</td> <td>215.175</td> <td>1505.05</td> <td>43.0327</td> <td>130.334</td> <td>115.176</td> <td>0.31333</td> <td></td> <td></td> <td></td>	13	2367.95	· ·		0733.03	0799.00	•	4.73300	1/01./1	200	125.557	125.557	215.175	1505.05	43.0327	130.334	115.176	0.31333			
2 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=1) 3 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=2) 5 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=3) 5 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=3) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=45) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=5) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=5) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=5) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=5) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=5) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=5) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=5) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=5) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=5) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=5) 7 - (Top Node Pressure=200) (Gas OI Rato=700) (Water Cut=5) 7 - (Top Node P	1 - (Top Node Press	ure=200) (Gas Oil Ratio=700) (Water Cut=0)	^	18	8851.75	8851.75	0	6.19622	1991.74	200	138.531	138.531	327.076	1455.15	59.3583	157.373	150.873	0.47759			No
3 - (1op Node Pressure=200) (Gas OI Ratio=700) (Water Cut=2) 4 - (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=4) 5 - (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=4) 7 - (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=4) 7 - (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=4) 7 - (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=4) 7 - (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=5) 7 - (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=5)	2 - (Top Node Press	ure=200) (Gas Oil Ratio=700) (Water Cut=11)	)	19	11522.9	11522.9	0	8.066	2291.49	200	150.619	150.619	493.381	1581.89	77.5219	157.629	196.72	0.73831			No
C (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=46) 7 - (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=56) 7 - (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=66) 7 - (Top Node Pressure=200) (Gas	3 - (Top Node Press 4 - (Top Node Press	ure=200) (Gas Oil Ratio=700) (Water Cut=22) ure=200) (Gas Oil Ratio=700) (Water Cut=33	)	~	45000	45000		10.5	2706.2	200	101.405	101.005	704.050	1714 60	00.0050	100 330	254.000				
6 - (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=55) 7 - (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=66) 7 - Case 1 (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=0)	5 - (Top Node Press	ure=200) (Gas Oil Ratio=700) (Water Cut=30)	ý	20	15000	12000	U	10.5	2/06.2	200	101.425	101.425	734.369	1/44.69	aa.825a	156.776	254.696	1			NO
7 - (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=66) Y = 5340 - Case 1 (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=0)	6 - (Top Node Pressure=200) (Gas OI Ratio=700) (Water Cut=55)																				
	7 - (Top Node Press	ure=200) (Gas Oil Ratio=700) (Water Cut=66)	) ~		Case 1 (Top N	ode Pressure:	=200) (Gas Oil F	Ratio=700) (Wa	ter Cut=0)				i								

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🔟 VLP (TUBING CURVE) CALCULATIONS (Well1A.out) (Matched PVT)																			
Done Can	cel Cages Calculate Plot Export	t Lift Curv	e <u>E</u> xport	Help		Generati	e Save F	Results	Transfer Data	GAP									
														1	1				
Top N	ode Pressure psig		Liquid Rate	Oil Rate	Water Rate	Gas Rate	VLP Pressure	WellHead Pressure	WellHead Temperature	First Node Temperature	dP Friction	dP Gravity	Total NoSlip Velocity	Erosional Velocity	C Factor	Maximum Grain	Erosion Rate	Corrosion Rate	Erosional Velocity Flag
	Water Cut 0 percent	Point														Diameter			
	Total GOR 800 scf/STB		(STB/day)	(STR/day)	(STR/day)	(MMecf/day)	(nein)	(osia)	(deg E)	(deg E)	(nei)	(nei)	(ft/sec)	(ft/sec)		(inches)	(0.001	(0.001	
Surface Equipmen	nt Correlation Beggs and Brill		(STD/day)	(STD/Udy)	(Sto/day)	(Hinschody)	(psig)	(psig)	(deg i )	(deg i )	(psi)	(psi)	(itysec)	(it/sec)		(incres)	(0.001	(0.001	
vertical Lit	Pate Mathed Uses Calasted		100	89	11	0.0623	2959.83	200	41.7848	41.7848	0.076605	2759.75	0.48442	133.296	1.45366	0.0031515			No
-	Pate Type Liquid Pate	2	130.176	115.857	14.3194	0.0811	2813.43	200	42.3244	42.3244	0.12223	2613.31	0.6657	136.956	1.94428	0.0037617			No
	First Node 1 Xmas Tree 600 (feet)	3	169.458	150.818	18.6404	0.10557	2598.22	200	43.0246	43.0246	0.21882	2398	0.87479	137.603	2.54295	0.0046161			No
	Last Node 8 Casing 9275 (feet)	4	220,594	196,329	24,2653	0.13743	2338, 12	200	43,9348	43,9348	0.41829	2137.7	1,14017	137.687	3.31234	0.0057147			No
Include Sand Cont	rol Pressur No																		
PE5	Stability Flag No	5	287.16	255.573	31.5876	0.1789	2111.14	200	45.118	45.118	0.74225	1910.39	1.487	137.816	4.3159	0.0071794			No
Enter Kates		6	373.814	332.694	41.1195	0.23289	1891.68	200	46.6559	46.6559	1.26334	1690.4	1.94014	137.973	5.62468	0.0090713			No
Reint	Liquid Rate	7	486.616	433.089	53.5278	0.30316	1714.93	200	48.6555	48.6555	2.09277	1512.82	2.53426	138.21	7.33453	0.011634			No
Point	(STB/day)	8	633,458	563,778	69.6804	0.39464	1588.75	200	51,2558	51,2558	3.39182	1385.32	3.31512	138,547	9.57111	0.015113			No
1	100	L.																	
2	130.176	9	824.611	733.903	90.7072	0.51373	1534.78	200	54.6373	54.6373	5.39024	1329.33	4.3445	139.012	12.5011	0.019751			No
3	169.458	10	1073.45	955.367	118.079	0.66876	1532.18	200	59.032	59.032	8.49909	1323.59	5.70645	139.637	16.3466	0.026098			No
4	220.594	11	1397.37	1243.66	153.711	0.87056	1533.9	200	64.7255	64.7255	13.4182	1320.31	7.51604	140.458	21.4044	0.034887			No
6	207.10	12	1819.04	1618 95	200.094	1 13326	1541.85	200	72 0202	72 0202	21 1962	1320.36	9 93086	141 507	28.0716	0.047581			No
7	486.616		1010101	1010100	2001051	1110020	10 12:00	200	7210202	1210202	2111302	1020100	5155000	111007	20.07.10	01017001			
8	633.458	13	2367.95	2107.48	260.475	1.47524	1559.84	200	81.1299	81.1299	33.4509	1325.88	13.1638	142.794	36.8749	0.066011			No
9	824.611	14	3082.51	2743.43	339.076	1.9204	1588.34	200	92.0322	92.0322	52.8814	1334.55	17.4946	144.28	48.5018	0.093597			No
10	1073.45	15	4012.69	3571.29	441.396	2.49991	1646.14	200	104.382	104.382	83.1839	1361.37	23.2783	145.869	63.8332	0.13534			No
11	1397.37	16	5222.56	4649.97	574 507	3 35439	1737.00	200	117 550	117 550	130 416	1404.9	30 9437	147 404	83.0608	0.20003			No
12	1819.04	<b>—</b>	5225,50	1010.37	374.332	5.25426	1/3/.33	200	117.555	117.555	130.410	1101.0	30.3437	147.404	03.9090	0.20005			NO
13	2367.95	17	6799.83	6051.85	747.981	4.23629	1876.24	200	130.83	130.83	202.509	1468.89	40.9987	148.711	110.278	0.30158			No
Sensitivity C	Cases ( 10 x 10 x 10 = 1000 cases )	18	8851.75	7878.06	973.692	5.51464	2081.02	200	143.52	143.52	312.051	1560.59	54.0072	149.595	144.409	0.46246			No
- 🔶 1 - (Top	Node Pressure=200) (Gas Oil Ratio=700) (Water Cu	19	11522.9	10255.3	1267.51	7,17874	2372.74	200	155,127	155,127	473,577	1684.9	70,5062	149.81	188,255	0.72122			No
2 - (Top Node Pressure=200) (Gas Oil Ratio=700) (Water Cu																			
	Node Pressure=200) (Gas Oil Ratio=700) (Water Cu Node Pressure=200) (Gas Oil Ratio=700) (Water Cu	20	15000	13350	1650	9.345	2/71.01	200	165.36	165.36	/05.925	1841.21	90.825	149.027	243.782	1			NO
🔂 5 - (fop Node Pressure=200) (Gas OII Ratio=700) (Water Cur																			
← 6 - (Top Node Pressure=200) (Gas Oil Ratio=700) (Water Cu < + Cuse 2 (Top Node Pressure=200) (Gas Oil Ratio=700) (Water Cut=11)																			
1																			

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#### Example: PVT tables from PVTsim





#### **Example: PVT tables from PVTsim**



CO. 3. (75)	DD ODDITON DN	mpopy loss smith	110 030	0.000	110.0	DOM: NO	03.0 10		
WAT.	ER-OPTION EN	TROPY GAS-WELL	US GAS	WITH	H20	DRY US	GAS - W		
	50 50 .	101355E-01							
	.209093E+06	.226757E+01							
	.965263E+05	177778E+02							
	.100000E+10	.100000E+10	.10	0000E	+10	.100	000E+10	.100000E+	1
	.100000E+10	.100000E+10	.10	0000E-	+10	.100	000E+10	.100000E+	1
	.100000E+10	.100000E+10	.10	00008-	+10	.100	0008+10	.100000F+	1
	1000008+10	1000008+10	10	00002	+10	100	0002410	10000024	
	1000002+10	1000002+10	10	000002	+10	100	0002+10	10000024	
	.1000002+10	.1000002110		00002		.100	0002110	10000021	1
	.100000E+10	.1000004410	- 10	00002	10	.100	0002410	.10000024	
	.100000E+10	.100000E+10	.10	0000E-	+10	.100	000E+10	.100000E+	1
	.100000E+10	.100000E+10	.10	0000E	+10	.100	000E+10	.100000E+	1
	.100000E+10	.100000E+10	.10	0000E-	+10	.100	000E+10	.100000E+	1
	.100000E+10	.100000E+10	.10	0000E-	+10	.100	000E+10	.100000E+	1
	.000000E+00	.000000E+00	.00	0000E-	+00	.000	000E+00	.000000E+	0
	.000000E+00	.000000E+00	.00	0000E	+00	.000	000E+00	.000000E+	0
	.000000E+00	.000000E+00	.00	0000E-	+00	.000	000E+00	.000000E+	0
	0000008+00	0000008+00	0.0	00002	+00	000	0005+00	00000074	ò,
	0000002100	0000002100		00000			0002100	00000021	
	.0000002+00	.000000E+00	.00	00002		.000	0002400	.0000002+	
	.000000E+00	.000000E+00	.00	OUDDE	100	.000	0002400	.0000002+	
	.000000£+00	.0000008+00	- 00	0000E	+00	.000	0005+00	.0000002+	2
	.000000E+00	.000000E+00	.00	0000E-	+00	.000	000E+00	.000000E+	U
	.000000E+00	.000000E+00	.00	0000E-	+00	.000	000E+00	.000000E+	0
	.000000E+00	.000000E+00	.00	0000E	+00	.000	000E+00	.000000E+	0
GAS	DENSITY (KG	/M3)							
	.802592E+00	.795453E+00	.78	8442E-	+00	.781	555E+00	.774790E+	0
	.768144E+00	.761613E+00	.75	5196E-	+00	.748	889E+00	.742689E+	0
	.736596E+00	.730605E+00	.72	4716E-	+00	.718	923E+00	.713197E+	0
	.707562E+00	.702016E+00	. 69	6556E-	+00	. 691	182E+00	.685890E+	0
	6806798+00	675547E+00	- 67	04938-	+00	665	514E+00	6606098+	ò
	655776R+00	651014E±00	64	6321E	100	641	6958400	63713684	n,
	6226412+00	6292092+00	61	20405-	+00	610	5215+00	61520154	ň.,
	6110007100	6060567100		20725			0542100	E0400451	
	.6110502+00	.0005502+00		20712	.00	. 550	5342400	. 35400424	
	.3303002400	.5071002400		40307	100		3032400	.57500124	
	.572131E+00	.500507E+00	. 50	4930E	+00	. 501	3972+00	.55/9092+	
	.2560/3E+01	.253/3/E+01	- 23	14465	+01	.249	1965+01	.246988£+	2
	.244820E+01	.242690E+01	.24	0599E-	+01	.238	544E+01	.236525E+	0
	.234542E+01	.232592E+01	.23	0676E-	+01	.228	792E+01	.226940E+	0.
	.225120E+01	.223329E+01	.22	1568E	+01	.219	836E+01	.218133E+	0
	.216458E+01	.214804E+01	.21	3172E-	+01	.211	565E+01	.209982E+	0
	.208423E+01	.206888E+01	.20	5375E-	+01	.203	885£+01	.202417E+	0
	.200969E+01	.199543E+01	.15	8138E-	+01	.196	752E+01	.195386E+	0
	.194039E+01	.192710E+01	.19	1400E	+01	.190	108E+01	.188834E+	0
	.187577E+01	.186337E+01	.18	5113E-	+01	.183	905E+01	.182713E+	0
	181537E+01	180376E+01	15	92308-	+01	178	0998+01	1769828+	ò.
	434634R+01	430571E+01	4.2	65878	+01	422	6798401	41884684	n 1
	415004E+01	4112922+01		22202	+01	404	2122+01	40072154	ň.,
	2072017101	2020227101	. 10	06100	01	207	2602101	2041655	
	. 3972916401	. 3535226401		400022	101	. 307	3602401	.30410521	
	.301024E+01	.3//93/E+01		4903E-	+01	. 371	9192+01	.3009052+	
	.366100E+01	.363263E+01	. 36	0472E	+01	.357	727E+01	.355027E+	υ.
	.352357E+01	.349724E+01	.34	7131E-	+01	.344	577E+01	.342062E+	0
	.339584E+01	.337143E+01	.33	4738E-	+01	.332	367E+01	.330031E+	0:
	.327729E+01	.325459E+01	. 32	3221E-	+01	.321	014E+01	.318838E+	0
	.316693E+01	.314576E+01	. 31	2488E	+01	.310	429E+01	.308397E+	0
	.306392E+01	.304413E+01	.30	2461E-	+01	.300	534E+01	.298632E+	0
	.616023E+01	.610119E+01	. 60	4334E-	+01	.598	665E+01	.593108E+	0
	.587660E+01	.582317E+01	. 57	7076E-	+01	.571	935E+01	.566890E+	0
	.561938E+01	.557078E+01	.55	2305E	+01	.547	619E+01	.543017E+	0
	538496E+01	534054E+01	50	96905-	+01	525	4015+01	521185E+	ñ
	5170418+01	5129678+01	50	99612-	+01	505	0228+01	50114954	ň
	4072202101	4025022101		00028	101	. 505	2402401	40265284	
	A791092+01	A75620P+01	. 40	2104P	+01	. 100	7002401	ACEAC224	
	.4/91096401	.4/36206401	. 4 /	0104E	101	.400	/332401	.40340324	<i>.</i>



#### Linear interpolation – 1D





#### Linear interpolation – 2D



#### Linear interpolation – 3D



$$egin{aligned} x_{ ext{d}} &= rac{x-x_{0}}{x_{1}-x_{0}} \ y_{ ext{d}} &= rac{y-y_{0}}{y_{1}-y_{0}} \ z_{ ext{d}} &= rac{z-z_{0}}{z_{1}-z_{0}} \end{aligned}$$

$$egin{aligned} c_{00} &= c_{000} \left(1 - x_{
m d}
ight) + c_{100} x_{
m d} \ c_{01} &= c_{001} \left(1 - x_{
m d}
ight) + c_{101} x_{
m d} \ c_{10} &= c_{010} \left(1 - x_{
m d}
ight) + c_{110} x_{
m d} \ c_{11} &= c_{011} \left(1 - x_{
m d}
ight) + c_{111} x_{
m d} \end{aligned}$$

$$egin{aligned} c_0 &= c_{00}(1-y_{
m d}) + c_{10}y_{
m d} \ c_1 &= c_{01}(1-y_{
m d}) + c_{11}y_{
m d} \end{aligned}$$

$$c=c_0(1-z_{
m d})+c_1z_{
m d}$$



### Advantages of using tables

- Faster than running the model
- Introduces no approximation errors (except interpolation)
- The O&G industry has extensive experience
- Easy to set up
- Can optimize software and license usage



# **Example: Gas-lifted well** including several constraints and using a table

SPE-202840 (ADNOC, UAE)





#### **Constraints:**

- 1. Dead (no flow)
- 2. Unstable flow (tubing heading)
- 3. Casing heading
- 4. Max CHP (1800 psig)
- 5. Min BHP (2750 psig)
- 6. Max oil (2080 bopd)
- 7. Hydrate formation in gas lift valve





Combinations (558 runs): Production choke opening: 5, 10, ...., 100% Gas lift rate: 0, 0.1,..., 3 MMscfd



## Excel file



### Issues with interpolation

- If system changes points usually must be generated again
- (Usually) requires regular grid
- Can be expensive to create the table
- Complexity grows with number of variables
- Logic (IF) and looping (FOR) is required to find the bounding values in the interpolation
- Handling discontinuities
- Be careful with the limits
- Number of points required
- Point spacing



#### Handling discontinuities



## Proxy models 2. Data-driven (NN)







## Production optimization: Limitations and pitfalls



- Model fidelity
- Is it actually possible to change the decision settings?:
  - Is the equipment/actuator functional and available?
  - Am I allowed to operate the control element?
  - Actuator response time



• Flat peak of optimum- more efforts give less results



SPE-166027-MS Multivariate optimization of production systems optimization Carroll and Horne ~  $^{\Box}$   ${
m NT}$ 

- Local optima
- Starting point
- Running time
- Short term versus long term optimization



(Khan academy)



• Short term versus long term optimization

Maximize NPV By changing  $q_o(t)$ 



Figure 3: Permeability (left) and porosity (right) distributions of the south wing.

#### Short term versus long term optimization





SPE-166027-MS Decision analysis for long term and short-term production optimization Applied to the Voador field, Agus Has

#### Short term versus long term optimization



Figure 9: Oil rate from production well PROD3 using different strategies; reactive control (blue), adjoint-based optimization (red), and the weighted-sum method (black).

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#### Take-aways when implementing prod optimization

- Look at the rest of the list first!
- Do we REALLY need to do optimization?
- Think carefully what is the main, most important, first order of magnitude problem

#### SLIDE 2

- Detect locations in the system with abnormally high-pressure loss and flow restrictions
- Verification of equipment design conditions vs actual operating conditions
- Identification and addressing fluid sources that have disadvantageous characteristics (e.g. high water cut, high  $H_2S$  content)
- Identify and correct system malfunctions and non-intended behavior
- Analyze and improve the logistics and planning of maintenance, replacement and installation of equipment or in the execution of field activities.
- Review the occurrence of failures and recognize patterns
- Calibration of instrumentation
- · Identification of operational constraints (e.g. water handling capacity, power capacity)
- Observe and analyze the response of the system when changes are introduced
- Find control settings of equipment that give a production higher than current (or, preferably, that give maximum production possible)
- Identify Bottlenecks
- Identifying and monitoring Key Performance Indicators (KPIs)



#### Take-aways when implementing prod optimization

- Define objective, constraints and variables
- Determine relevance of constraints
- Is it realistic to modify optimization variables?
- Formulate your optimization in a smart way (choose the right variable)
- Study how your input affects your results



## THE END THANK YOU

