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A Comparative Model to Differentiate Between the Production from Vertical and Horizontal Wells in Bilciuresti Gas Field

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Abstract

In this paper, a comparative model is developed using solidworks flow simulation in order to differentiate between two extraction systems (one horizontal well and six vertical wells) for Bilciurești deposit through three various simulations cases: 6 vertical wells extraction system, a horizontal well extraction system of 7" casing, 5.5" tubing and extraction through tubing, and the horizontal well extraction system with 7.625" casing, 5.5" tubing, extraction through tubing and casing). Obviously, the erosion velocities of gas are compared to its flow velocities. Additionally, a sensitivity analysis is performed to study the influence of changing nozzle sizes on production. It has been found that, in all situations, the allowable erosion rate is higher than the gas flow rate, except in the case where no extraction nozzle is used. Also, the higher gas velocity; the bigger nozzle diameter, but it remains below 10 m/s (10.25 m/s at the nozzle of 30 mm) and it is below the erosion rate. If no adjustment nozzle is used, the flow rate increases excessively and the speed exceeds the erosion limit. At a 30 mm nozzle, an extraction flow rate of 1068.57 mSm^3/day (extraction only through tubing) was obtained, comparable to the flow rate of the six vertical wells (1087.8 mSm^3/day).

Keywords*: Horizontal well; Bilciurești field; Vertical wells; Comparative study; Recovery increase.*

1. Introduction

A horizontal well is a wellbore drilled with an inclination angle between 80° and 100° but the ideal horizontal well is which has a deviation of 90°. Applications of the horizontal well have broadly increased all over the world. They include increasing production rate, adding low cost reserves, improvement of economic benefit, acceleration of reserves etc. In order to achieve the above applications, it required to [1]:

- Decrease unwanted fluid production and thereby, reduce surface facility cost;
- Produce "lost" reserves in thin oil rim;
- Reduce the number of injection and production wells required for development of a new field, redevelopment of a mature field or infill drilling;
- Bring on-stream presently unexploited wells by sidetracking.

The horizontal well technology was utilized with limited applications in the early 1980's. However, by the 1990's, it has become accepted in the oil industry and has extensively increased [2-5]. Based on the field results of the horizontal well, the stabilized productivity of the horizontal well is 2 to 5 times more than a vertical well's productivity. Additionally, the horizontal wells add considerably to the petroleum production in several oilfields. About 30% of the production from the Norwegian sector of the North Sea is achieved due to horizontal wells. Likewise, additional oil is produced by horizontal wells rather than by vertical wells in a number of reservoirs in Denmark. In Saudi Arabia, 5 to 10% recovery improvement is increased due to horizontal drilling i.e., close to 12.5 to 25 billion barrels of additional recovery. In the Zakum Field in UAE, over 50 horizontal wells added about 26 MMSTB of oil production by the end of 1993, about 25% of field production. Furthermore, the horizontal well projects are succeeded in offshore fields in China and India [6-15]. Recently, at the level of the world oil and gas industry, the drilling of horizontal wells has increased in increasing numbers. In Romania, this type of well was drilled, especially in the areas of Independența-Galati County and Vața-Argeș County. The horizontal drilling is a much more complex process, from all points of view, which is done in various and special conditions compared to vertical drilling. It also involves much higher costs, but which have proven to be cost-effective compared to the much higher level of production obtained. Therefore, for the realization of a horizontal path, it is recommended to use rotary steerable systems and LWD type recording systems, which offer the facility to record certain values of the formation such as resistivity, gamma radiation values, density values and porosity of the formation or compression and shear values.

Therefore, in this paper, a comparative model is developed to differentiate the extraction and production of six vertical wells drilled in the past on the Bilciurești structure with the simulated path of a horizontal well drilled at approximately the same depth on the same structure.

2. Model procedures

In order to build a model to compare between the production from a horizontal well and certain number of vertical wells, the proposed procedures shown in Figure 1 are modeled and validated by SolidWork Flow Simulation and LMS Amesim software for Bilciurești deposit field.

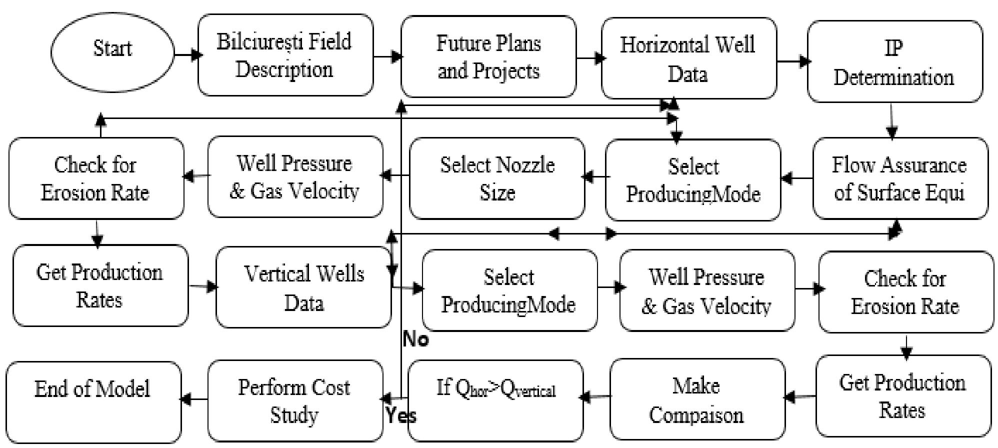


Figure 1. Model flow schema

3. Bilciurești deposit field description

The Bilciurești structure is located in Dâmbovița County, about 40 km W-NW of Bucharest, Romania for ROMGAZ Company. The fixed assets that contribute to the gas storage process are the following:

- 61 wells of which 57 injection / extraction wells, 3 piezometric wells, 1 soda waste water injection;
- Surface infrastructure consists of: Butimanu gas compression station; 7 gas drying stations; 26.5 km collecting pipes related to the 57 injection / extraction wells; 50 well gas heaters; 24 impurity separators; 14 gas technological measurement installations; 37.5 km of collecting pipes; bidirectional panel of fiscal measure; and wastewater injection station.

The company wants to develop and modernize the gas storage Bilciurești deposit. The project aims to increase the daily gas delivery capacity of the Bilciurești deposit to 20 million m^3/day and ensuring an increased degree of operational safety. This project includes [16]:

a. Necessary investment works:

- Modernization of separation, measurement and drying installations for Bilciurești groups;
- Systematization and modernization of pipeline system and cooling system Butimanu Compression Station;
- Modernization of 19 injection / extraction wells;

- Drilling 4 new wells;
- 16” Bilciurești - Butimanu gas pipeline.

b. Estimated completion deadline: 2025;
c. Estimated total value of the project: 271.15 million lei (around 56 million euros).

Therefore, our work here is to do a comparative study between one horizontal and 6 vertical well in order to convince the company to choice our approach. The layouts of horizontal well and six vertical wells are shown in Figure 1. The characteristics of the vertical wells of Bilciu-rești deposit are illustrated in Table 1. The reservoir is gas reservoir with pressure (Pr) of 1.25E07 Pa, and temperature of 313.15° K.

Table 1. The characteristics of the vertical wells Bilciurești deposit

Well Nr.	Pr, bar	Pf, bar	Q, mSm^3/day	PI, $mSm^3/day/kPa^2$	Perfora-tions, m	Nozzles, mm
17	125	117.05	278.674	14.48E-6	29	16.5
105	125	106.69	158.206	3.72E-6	12	12
145	125	113.90	71.516	2.69E-6	8	7.5
149	125	107.57	227.009	5.60E-6	8	15.1
169	125	100.55	90.94	1.97E-6	11	8.9
171	125	107.32	260.828	8.67E-6	30	16.3
		TOTAL	1087.18			
			Average	6.19E-6	16.33	12.716
				3.792E-7	$mSm^3/(day.kPa^2\ m)$	

mSm^3 /day means millions standard cubic meters per day

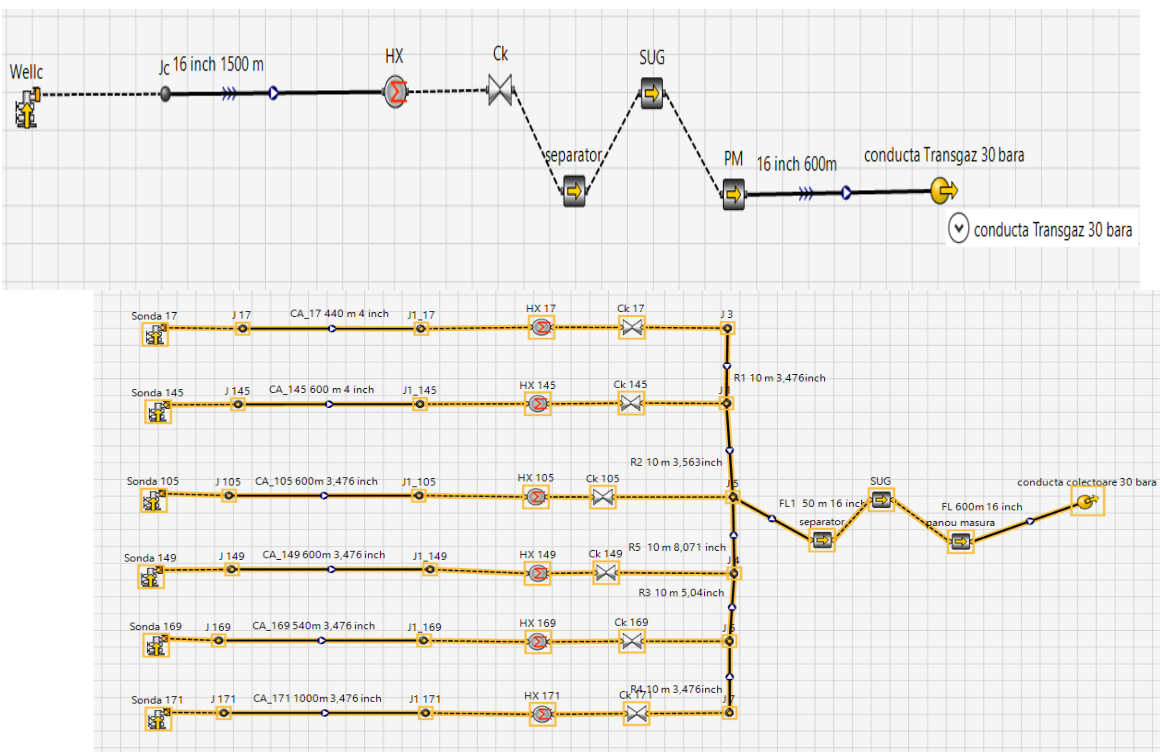


Figure 2. Horizontal well layout (well C), and vertical wells'layouts (sonda 17, 105,145, 149, 169, 171)

4. Model results and analysis

Building a model to differentiate between the production of a horizontal well and vertical wells drilled in Bilciuresti deposit is significantly desirable and important because the ROMGAZ company has planned to spend 56 million euros to develop that deposit. That`s why, our study is highly important to select the optimum scenerio for drilling new wells. Here, the model is developed to compare between a simulated horizontal well and actual six vertical well drilled in the same structure. The image of the horizontal well model with its surface equipment is shown in Figure 1 and it`s called well C. Moreover, the image of the 6 vertical wells with their surface equipment is appeared in Figure 2 and wells are called Sonda 17, 105,145, 149, 169, and 171.

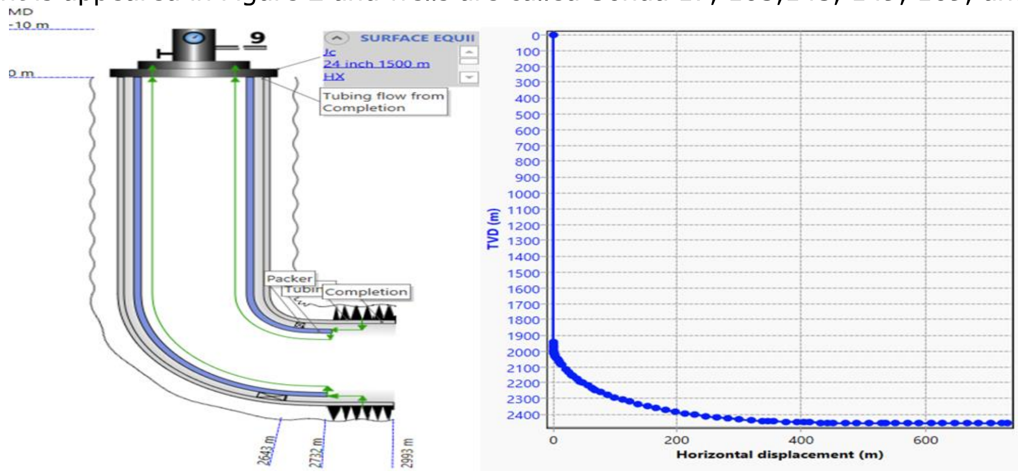


Figure 3. Horizontal well (Well C) geometry and trajectory

Table 2. Characteristics of casing and tubing for well C

Case No.	Item	OD, in	ID, in	t, mm	N.wt, kg/m	Ra, mm	Type
1	Casing (API)	7	6.366	0.0080518	34.22777	2.54E-05	C75
	Drillpipe	5.5	4.778	0.0091694	32.59079	2.54E-05	E75
2	Casing (API)	7.625	6.375	15.875	70.09252	2.54E-05	C75
	Drillpipe	5.5	4.778	9.1694	32.59079	2.54E-05	E75

For the proposed horizontal well, the suggested geometric shape is shown in Figure 3 with the properties of casing and drillpipe descriped in Table 2. Additionally, wellbore trajectory are selected and optimized based on the principles and methods presented by Halafawi and Avram [18]. The final wellbore trajectory is plotted in Figure 3. From the flow assurance calculations, the pressure drops considered on the surface equipment are: 0.1 bar heater (20 K gas heater); 0.1 bar separator; SUG 0.3 bar; 0.1 bar measuring panel; pressure at the transport pipes 30 bar. In order to determine the productivity index (PI) of well C, the average productivity index of the 6 vertical wells is divided by the average perforations of the vertical wells, and it equals 3.7917E-07 mSm^3/day /kPa^2. The average perforations of the vertical wells is estimated at 16.33 m and the productivity indices of the vertical wells are averaged and equal 6.19E-06 mSm^3 /day/ kPa^2 (Table 1).

4.1. Case 1 Horizontal well model with 7 in casing, 5.5 in tubing, tubing extraction only (Table 2)

This is the system shown in Figure 3, with a 12.7 mm nozzle (the nozzles were averaged at the vertical wells). The gas velocity is below the imposed limit of 10 m/s (Figure 4-a). The obtained gas flow 219.61 mSm^3/day. The gas velocity is below the erosion limit (Figure 4-b). Above the erosion rate, the pipe material is destroyed and, in particular, the layer deposited inside is degraded, which increases the corrosion resistance. Further, the same conditions occur during changing the nozzle size to 25 mm. The gas velocity is below limits and reaches to 7 m/s maximum value and the resulted flow rate is 787.92 mSm^3/day (Table 4). However, changing nozzle size to 30 mm results higher gas speed above the imposed limit of 10 m/s at the exit from the tubing, where it reaches the value of 10.25 m/s. Otherwise the speeds are below this limit. The obtained gas flow 1068.57 mSm^3/day. The gas velocity is also below the erosion limit. On the other side, if the system shown Figure 3 is working without the nozzle, the same situation of 30 mm nozzle size is repeated but with different values. The gas speed reaches 65 m/s on the tubing and still above the imposed limit of 10 m/s (Figure 5-a). The obtained gas flow is then 2278.94 mSm^3/day (Table 4). The erosion rate is below the value of the gas velocity. In other words, the tubing is not suitable for the high gas flow obtained through the horizontal well (Figure 5-b).

4.2. Case 2: Horizontal well model with 7.625 in casing, 5.5 in tubing extraction by tubing and casing (Table 2)

Pressure drops are considered the same as case 1 for surface equipment. The geometric characteristics of the well are given in Figure 3, except for the casing which is 7.625 in instead of 7 in. In this system shown in Figure 2, the gas speed is below the imposed limit of 10 m/s with the 12.7 mm nozzle size (Figure 6-a). The gas flow obtained 220.31 mSm^3/day. The erosion rate is above the value of the gas flow rate as shown in Figure 6-b. Using bigger nozzle sizes than 12.7 mm such as 25, 30, and 35 results the same flowing conditions behavior with various values. Moreover, the gas flow rate increases with increasing the nozzle size (Table 4). However, the behavior of gas flow is inverted without installing the nozzle on the well head. The gas speed becomes above the imposed limit of 10 m/s, the value of 60.94 m/s on the tubing is reached (Figure 7-a). The erosion rate is below the value of the gas velocity as shown in Figure 7-b. The obtained gas flow is therefore 3178.84 mSm3/day (Table 4).

a.

b.

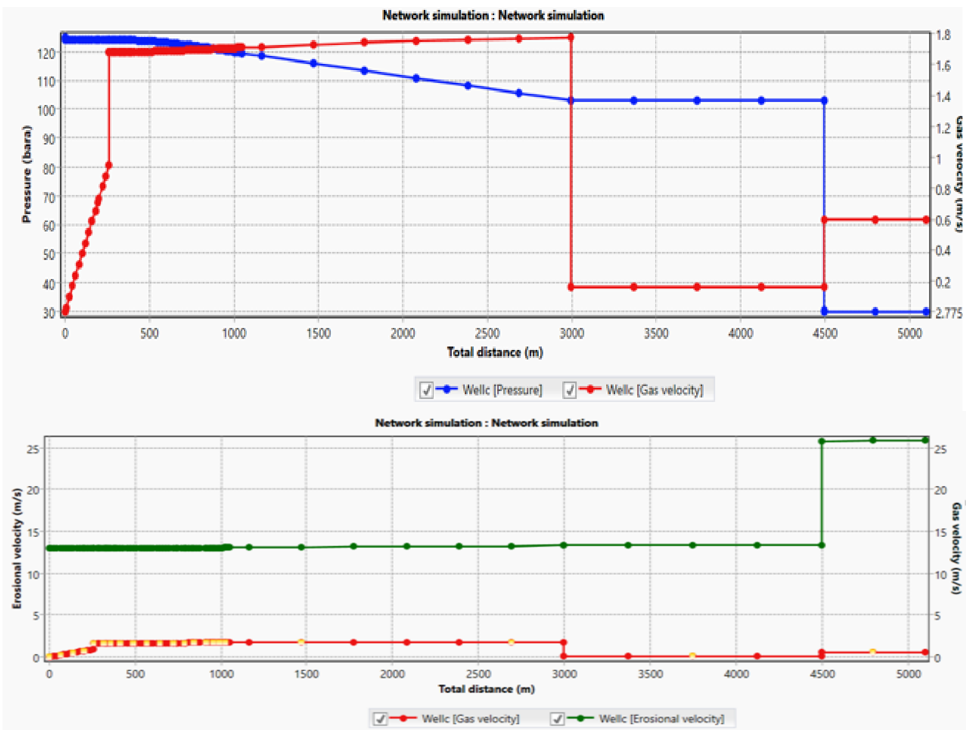
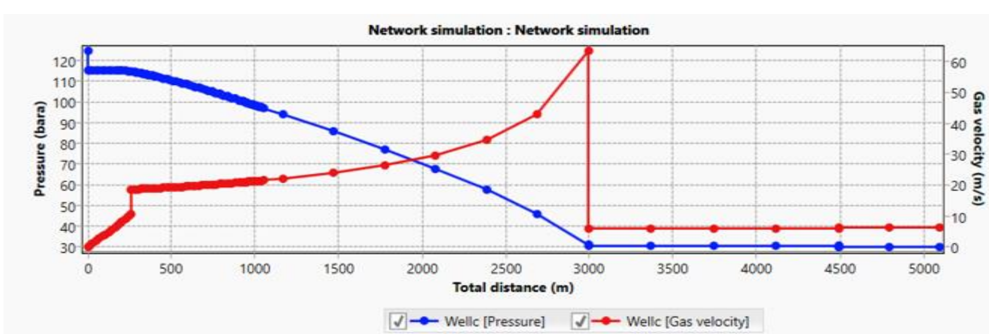


Figure 4. Gas parameters variation of well C with 12.7mm nozzle: a. Gas speed and pressure distribution; b. Gas velocity and erosion velocity distribution- Case 1

a.



b.

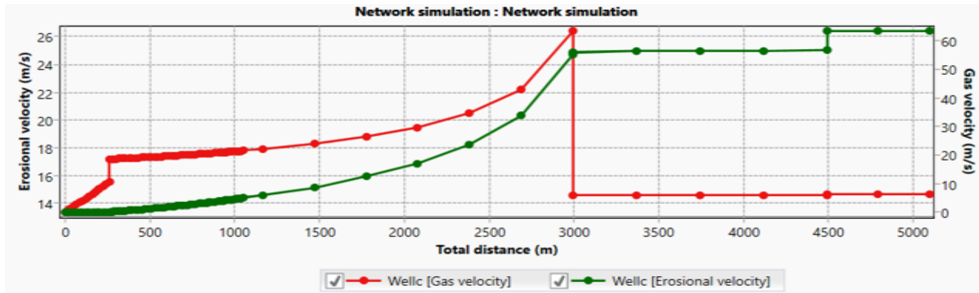
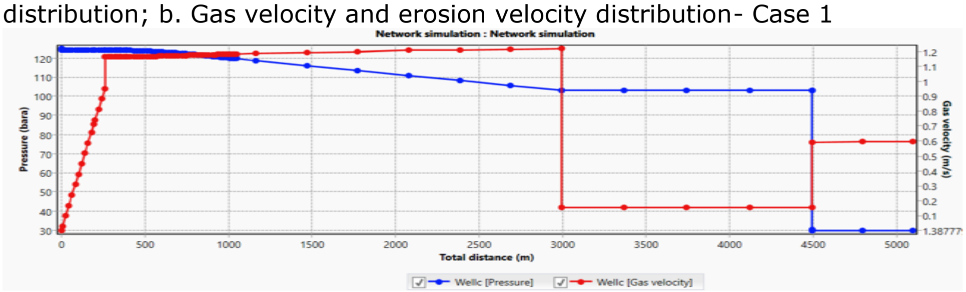


Figure 5. Gas parameters variation of well C without nozzles: a. Gas speed and pressure distribution; b. Gas velocity and erosion velocity distribution- Case 1

a.



b.

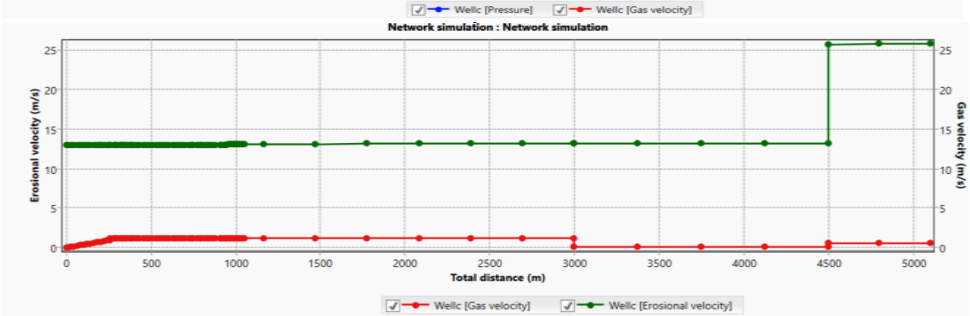
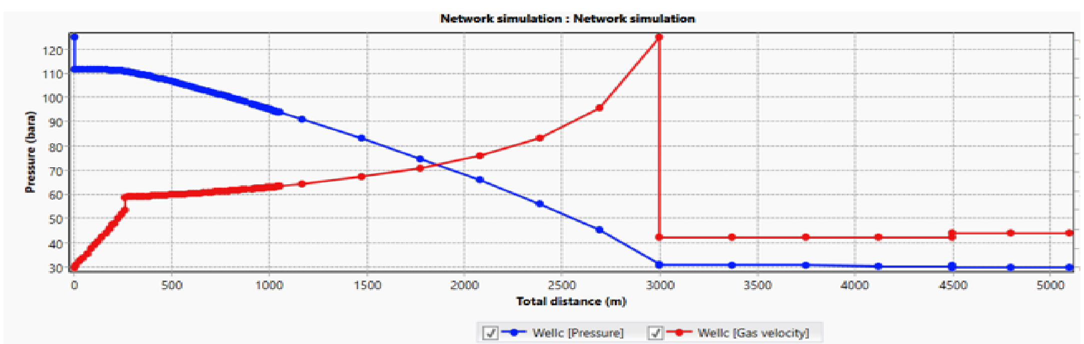


Figure 6. Gas parameters variation of well C with 12.7 nozzle size: a. Gas speed and pressure distribution; b. Gas velocity and erosion velocity distribution- Case 2

a.



b.

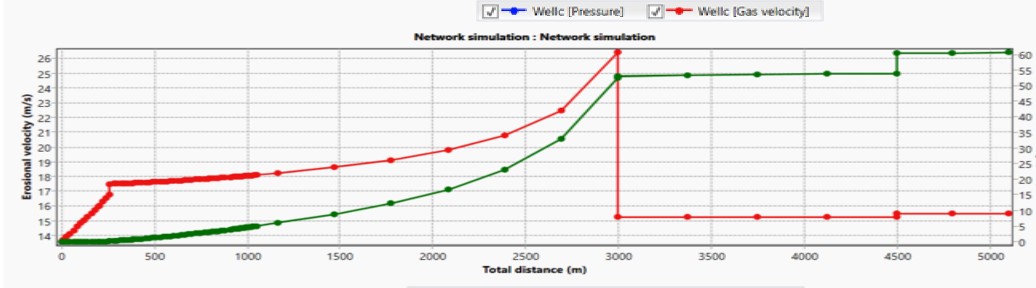


Figure 7. Gas parameters variation of well C without nozzle size: a. Gas speed and pressure distribution; b. Gas velocity and erosion velocity distribution- Case 2

4.3. Case 3: Building the model with six vertical wells

The characteristics of the vertical wells are given in Table 2. The image of the model with 6 vertical wells, which are called sonda 17, 105,145, 149, 169, and 171, is given in Figure 3. Pressure drops considered on equipment are: 0.1 bar heater (20 K gas heater); 0.1 bar separator; SUG 0.3 bar; 0.1 bar measuring panel; pressure at the transport pipes 30 bar. The geometric characteristics of the vertical wells and the parameters of the pipes are given in Figure 13 and Table 3. The model and simulations are developed and performed for Fluid with 100% methane and extraction only by tubing. The results of the model are shown in Figures 14 through 19. The gas velocity is found below the required limit of 10 m/s at 3 wells: Sonda 105, 145, and 169 (Figure 14-a) while the gas velocity exceeds 10 m/s at wells 17, 149, and 171 on the tubing and the gas speed is reached to 12.5 , 11, and 12.5 m/s) for wells 17, 149, and 171 respectively (Figures 15-a). Figures 14-b and 15-b show the gas erosion rates compared to the gas flow rate. It is observed that the permissible erosion rate is higher than the gas flow rate in all situations. Regarding the production rate comparison, flow rate is 1068.57 mSm^3/day at the horizontal well with a 30 mm nozzle size which is equivalent to that of the model with 6 vertical wells at the same time (Table 4). Gas velocity is still below the erosion limit. The gas flow obtained with the 6 vertical wells is 1087.18 mSm^3/day (Table 4).

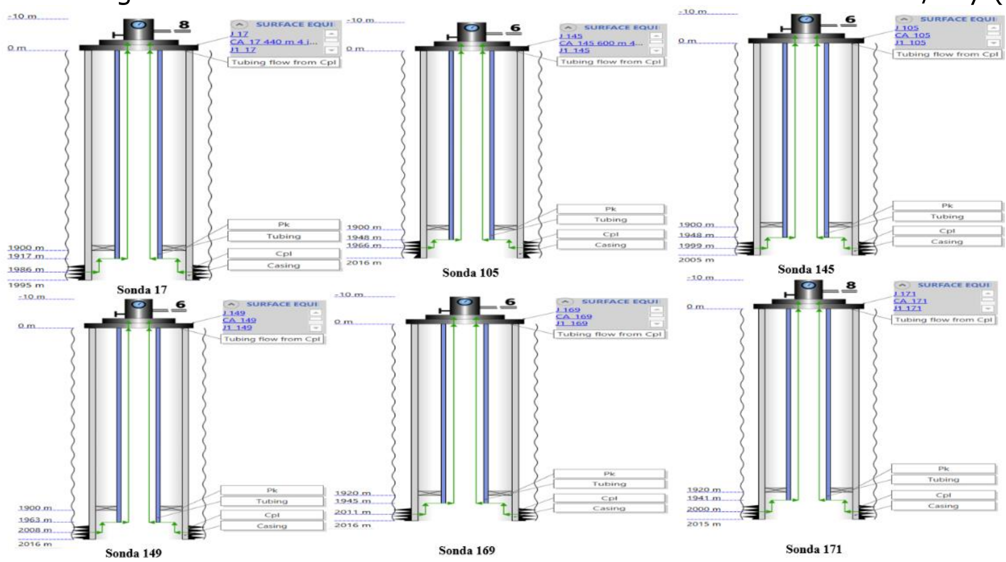
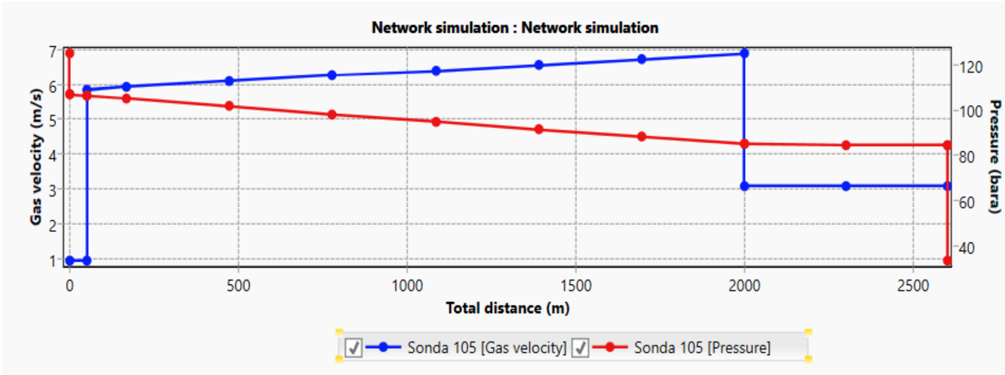


Figure 13. Geometric characteristics of the vertical wells

Table 3. Characteristics of casing and tubing for well C

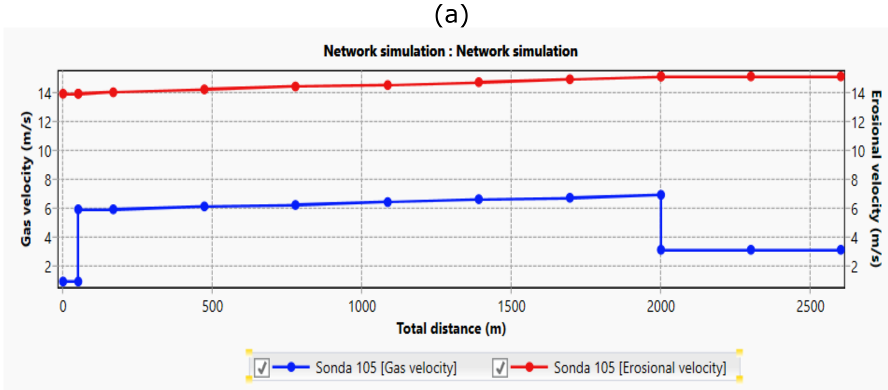
Well No.	Item	MD, m	ID, m	Thickness, m	Roughness, m
17	Casing	1995	0.1470914	0.0105918	2.54E-05
	Tubing	1916.77	0.0590042	0.0070104	2.54E-05
105	Casing	2005	0.1470914	0.0105918	2.54E-05
	Tubing	1947.8	0.0590042	0.0070104	2.54E-05
145	Casing	2016	0.1470914	0.0105918	2.54E-05
	Tubing	1947.8	0.0590042	0.0070104	2.54E-05
149	Casing	2016	0.1470914	0.0105918	2.54E-05
	Tubing	1963	0.0590042	0.0070104	2.54E-05
169	Casing	2016	0.1470914	0.0105918	2.54E-05
	Tubing	1944.89	0.0590042	0.0070104	2.54E-05
171	Casing	2015	0.1470914	0.0105918	2.54E-05
	Tubing	1940.55	0.0590042	0.0070104	2.54E-05

a.



b.

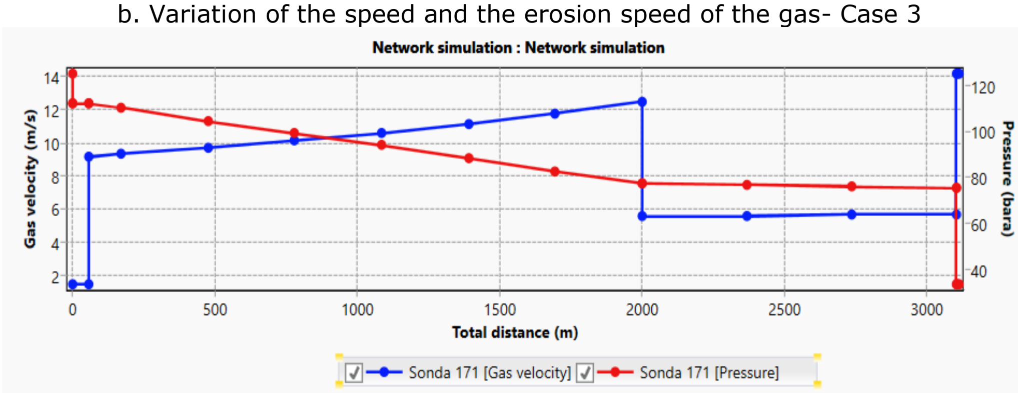
(a)



(b)

Figure 14. Gas Characteristics at well 105: a. Variation of gas velocity and pressure; b. Variation of the speed and the erosion speed of the gas- Case 3

a.



b.

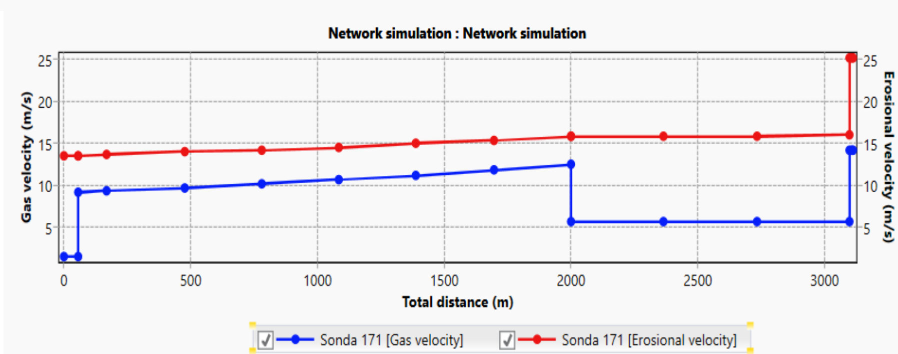


Figure 15. Gas characteristics at well 171: a. Variation of gas velocity and pressure; b. Variation of the speed and the erosion speed of the gas- Case 3

Table 4. Comparison between well C and vertical wells

6 Vertical Wells Case 3			Horizontal Well C Case 1			Case 2	
Well	Total Gas Rate MSm^3/day	Pressure Pa.a	Nozzle Size mm	Pressure Pa.a	ST Gas Rate MSm^3/day	Pressure Pa.a	ST Gas Rate MSm^3/day
17	278.6747	7928782	12.7	10317870	220.3145	10305440	219.6132
105	158.2067	8475575	25	9912477	809.0681	9665645	787.9285
145	71.51668	9711760	30	9563727	1121.415	9118024	1068.574
149	227.0095	7705266	35	9091888	1450.195		
169	90.94493	8805960	Without	3123471	3178.842	3106900	2278.94
171	260.8288	7691173					
	1087.18131						

5. Model discussion and extracted conclusions

In this article, two extraction systems are compared: with a horizontal well (Figures 1,2 and Table 2), with 6 vertical wells (Figures 1,12 and Table 3). Three simulations are performed (Table 4):

- Case 1, for the extraction system with a horizontal well: 7 in. Column, 5.5 in tubing, extraction only by tubing; the simulation is done with a 12.7, 25, 30 mm nozzle sizes, and without adjusting nozzle.
- Case 2, for the extraction system with a horizontal well: 7.625 in column, 5.5 in tubing, tubing and casing extraction; the simulation is done with a 12.7, 25, 30, 35 mm nozzle sizes, and without adjusting nozzles. Gas speeds decrease in case 2 compared with case 1: 12.7 mm (maximum 1.2 m / s compared with 1.8 m /s), 25 mm (maximum 4.8 m/s compared with 7.1 m/s), 30 mm (maximum 7 m / s compared with 10.25 m / s); without nozzle (maximum 61 m/s compared with 65 m/s), but It should be noted that in the last two situations the flows has increased significantly compared with the first case.
- Case 3, the simulation is done for the extraction system with 6 vertical wells
- Regarding the horizontal well (well C), case 1, it is found that, with the increase of the nozzle diameter, the extracted flow increases: 12.7 mm (219.61 mSm^3/day), 25 mm (787.92 mSm^3/day), 30 mm (1068.57 mSm^3/day), without nozzle (2278.94 mSm^3/day). The gas velocity increases with the nozzle diameter, but remains below 10 m/s (10.25 at the 30 mm nozzle) and is below the erosion rate. If the control nozzle is not used, the flow becomes very high 2278.94 mSm^3/day and the speed exceeds the erosion limit. It is also found that the more nozzle diameter, the more extracted flow rate: 12.7 mm (220.31 mSm^3/day), 25 mm (809.06 mSm^3/day), 30 mm (1121.41 mSm^3/day), and without nozzle (3178.84 mSm^3/day).
- Regarding the vertical wells, in case 3, the gas velocity is below the imposed limit of 10 m/s, at 3 wells: 105, 145, and 169. The gas velocity exceeds 10 m/s on the tubing reaching the gas speed to 12.5, 11, 12.5 m/s for wells 17,149, and 171. It is also observed that, in all situations, the permissible erosion rate is higher than the gas flow rate. Moreover, the gas flow obtained from the model with 6 vertical wells and the overall scheme is 1087.18 mSm^3/day.
- At a nozzle of 30 mm, an extraction flow of 1068.57 mSm^3/day for well C is slightly low compared to the flow of the 6 vertical wells 1087.18 mSm^3/day.
- A solution to reduce the extraction flow rate is the use, in parallel, of the tubing and the column, case 2.
- Using the extraction system with the tubing and the casing in parallel (case 2), increasing the nozzle size to 35 mm leds to obtaining again a case with speeds below the imposed limit of 10 m/s, and the flow rate is being 1450.19 mSm^3/day, ie 1.33 extraction flow with 6 vertical wells (1087.18 mSm^3/day).

References

[1] Joshi SD, Ding W. Horizontal Well Application: Reservoir Management. SPE International Conference on Horizontal Well Technology, Calgary, 18-20 November, 1996.
[2] Joshi SD. A Review of Horizontal Well and Drainhole Technology. SPE Annual Technical Conference and Exhibition, Dallas Texas, Sep 27-30, 1987.
[3] Bosio JC, Fincher RW, Giannesini JF, Hatten JL. Horizontal Drilling - A New Production Method. 12th World Petroleum Congress, Houston, Texas, April 1987.
[4] Cade RW, Joshi SD. Horizontal Technology Matures into Fundamental Drilling Technique. American Oil and Gas Reporter, July 1996, 36-42.
[5] Ding W, Lacy S, Joshi SD. Key Parameters for Economic Success of Horizontal Wells. Southwestern Petroleum Short Course, Lubbock Texas, April 17-18, 1991.
[6] The Norwegian petroleum Directorate Newsletter on Improved Oil Recovery, (Nov. 1995) No. 5, Stavanger, Norway.
[7] Mortensgaard A. Economic New Technology Improve Danish Offshore Oil Recovery. Oil & Gas Journal, Jun. 10, 1996, 58-63.
[8] Aalund L, Rappold K. Horizontal Drilling Taps More oil in the Middle East. Oil & Gas Journal, Jun. 21, 1993, 47-51.
[9] Muhairy A A, and Farkl E A. Horizontal Drilling Improves Recovery in Abu Dhabi. Oil & Gas Journal, Sep.13, 1993, 53-57.
[10] Siddiqui TK, Al Khatib HM, Sultan AJ. Utilization of Horizontal Drainhole in Developing Multilayered Reservoir. SPE Middle East Oil Show, Bahrain, March 11-14, 1995.
[11] Gray GE, Hall KH, Huang CM. Batch Drilling Program Cut, Time, and costs for Liuhua Development. Oil& Gas Journal, Aug. l2, 1996, 69-76.
[12] Gu K, Ye Y. Tests Verify Advantages of Horizontal Wells in Offshore China Oil Fields. Oil & Gas Journal, Oct. 19, 1992, 76-80.
[13] Peng CP, Bateman CF, Kaffenes JM, Yanosilk JL, Liu HM. Extended Production Tests in the Liuhua 11-1 Reservoir. SPE Reservoir Engineering, Aug., 1994, 169-174.
[14] Sinha PK, Vij SK, Walia A, Khan AA. Performance Evaluation of Horizontal Wells in Bombay Offshore. SPE/CIM 5th Annual One Day Conference on Horizontal Wells, Calgary, Canada, Nov. 21, 1995.
[15] Srinivansan S, Joshi JM, Narasimham JL, Rae VM, Barua S, Jha KN. Feasibility of Development of Marginal Fields Through Horizontal Well Technology. SPE/DOE 10th Symposium on Improve Oil Recovery, Tulsa, April 21-24, 1996.
[16] ROMGAZ SA, DEPOGAZ Ploiești SRL. Evaluation report of the activity for 2018 and 2019. Document approved by the Decision of the Board of Directors no. 8 at 29.05.2019.
[17] Halafawi M, Avram L. Wellbore trajectory optimization for horizontal wells: the plan versus the reality. J. Oil Gas Petrochem. Sci., 2019; 2(1), 49-54.
[18] Lyons W, Plisga G.Standard Handbook of Petroleum & Natural Gas Engineering. Gulf Professional Publishing, Second edition, Houston, USA, 2011.
[19] Avram L. Foraj Dirijat. Editura Cartfil, 1999.
[20] Rădăcină D, Halafawi M, Avram L. Casing Wear Prediction in Horizontal Wells. Petroleum and Coal J., 2020; 62(2) 395-405.
[21] Dinu F. Extracția și Prelucrarea Gazelor Naturale. Editura Universității Petrol-Gaze din Ploieşti, 2013, ISBN 978-973-719-517-3.
[22] Joshi SD. Horizontal Well Technology. PennWell Books, 1991, 535 pages.

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