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Simulation of the Steam Pipeline Network in the Monteverdi Geothermal Field

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Keywords

Monteverdi geothermal field, Numerical simulation, steam pipeline network, steam scrubbing

ABSTRACT

This report describes the results of a numerical simulation of a steam pipeline network in Monteverdi geothermal field.

This model evaluates pressure drops, temperature distributions, mass and energy flow rates, steam qualities, non condensable gas content, heat losses along the pipeline network using as an input the well and turbine characteristic curves.

Since the thermal characteristics of the new well W16 were not known, its dynamic temperature wellbore profile was simulated by means of another computer model in order to evaluate the wellhead superheating.

This piece of information was needed to decide the configuration of the pipeline and the location of the scrubbing unit.

In particular, this work aimed at:

- defining new configuration of the steam pipeline network
- simulating the thermodynamic conditions in all its branches.

Once the general network layout was defined, an optimization of the relevant parameters was carried out. The simulation pointed out a branch in which pressure losses were excessive.

Introduction

The Monteverdi field is located south-west of Larderello (Figure 1).

Only a small number of wells produce saturated steam from phyllities at -1500 m a.s.l.; all the other wells produce superheated steam from gneiss localized between -2300 and -3500 m a.s.l., at a temperature of about 300°C.

The productive wells are 19 over a total of 23 drilled wells; the remaining 4 ones are used for reinjection or as reinjection reserve. In 2005, the well W16 was drilled in order to find additional geothermal fluid in deep formations (metamorphic substratum) where a higher pressure exists.

In precedence, promising results were obtained from well W15 (about 50 t/h). The W16 well performance had been evaluated only on the basis of a short production test (ten days). The characteristic parameters at the end of this production test were:

- flow rate: 95 t/h;
- flowing pressure: 8 barA;
- temperature: saturated;
- NGC: 1.22 % by weight.

Description of the Steam Pipeline Network

In the Monteverdi zone, 2x20 MW geothermal units are installed (PP1 and PP2).

The turbine inlet pressures of PP1 and PP2 are respectively 7 and 5 barA.

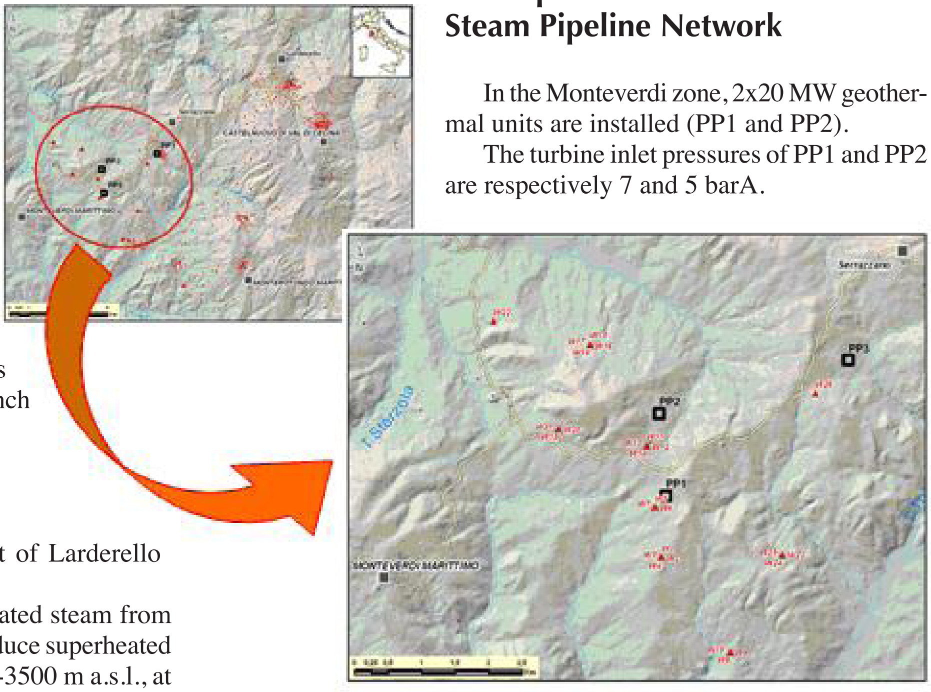

Figure 1. Monteverdi geothermal field.

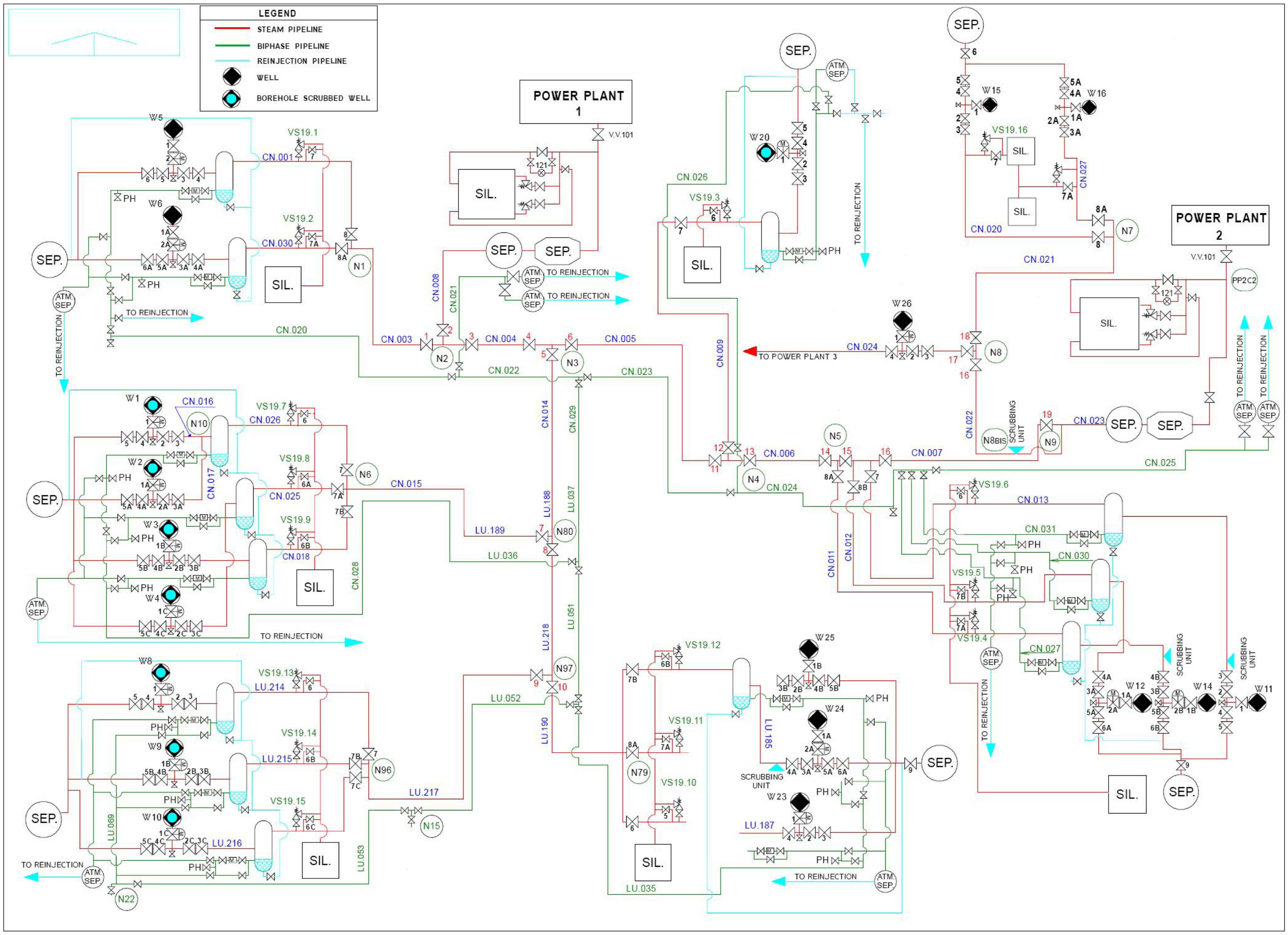

Figure 2. Monteverdi steam pipeline network.

The pipeline network is fed by 11 wells and supplies steam to both power plants. At present, no interconnection exists between PP1 and PP2 pipeline networks (valve number 15 is closed; see Figure 2).

The Monteverdi geothermal fluid has a high chloride concentration (>100 ppm).

A steam scrubbing unit (NaOH solution sprinklers and separators) is placed upstream PP2 power plant in order to eliminate HCl. As for the wells feeding PP1 power plant, the alkaline solution is injected into the wellbores to avoid corrosion both in the wells and in the pipelines. In this second configuration, a separator is placed at each well head.

W11 and W12 wells, which feed PP2 power plant, are scrubbed on the same pad and are conveyed downstream the power plant scrubbing unit. PP2 power plant is fed also by W26 well, which can feed PP3 power plant too, according to operation requirements.

Description of the Network Simulator

This simulator has been developed for simulation and performance analysis of a geothermal pipe network. It is a steady state, single-phase fluid flow simulator developed in ENEL and is the evolution of the preceding simulator VAPSTAT1 (Marconcini and Neri, 1979).

A nonlinear numerical method is used for solving the mass and energy balance equations. This model adopts the Newton-Raphson method to calculate pressures and flow rates at each node.

A specific nomenclature was developed in order to identify each pipeline and well. The necessary input data must be supplied accordingly to this scheme:

- Wells: number, type, wellhead pressure, temperature, gas steam ratio chloride concentration, laminar and turbulent flow parameters.
- Pipelines: number, diameter, length, friction factor.

A name is assigned to each node and pipeline. There are 3 type of nodes:

- simple (flow rates are balanced).
- imposed pressure (wells and turbines).
- imposed flow rate .

The heat transfer coefficient [W/m] for each diameter can be chosen. A wellhead curve for each well can be given, as well as the flow coefficient (t/h/bar) for each turbine. A number of throttled valves can be taken into account.

The results are written to an output text file that shows all the thermodynamic values for all the nodes (flow-rate, pressure, temperature, gas steam ratio, enthalpy, specific volume and chloride concentration). For each pipeline, the flow-rate, pressure loss, average temperature, gas/steam ratio, specific volume, enthalpy at the two nodes and chloride flow rate [kg/h] are calculated.

Aim of This Work

The scope of this work was to investigate the feasibility of connecting the new well W16 to the existing pipeline network and to forecast its contribution in terms of MW. To accomplish this task, the following steps had to be taken:

- simulation of the Monteverdi pipeline network before the connection of W16 well (base case).
- simulation of the wellbore temperature profile to decide the need and the location of the scrubbing unit.
- simulation of the new scenario after the introduction of the new well.

Based on these results, decisions can be taken on the following items:

- necessity of shutting or rerouting some wells
- pipeline modifications in critical points

Simulation Results of the PP2 Network (Base Case)

The experimental data, taken before the introduction of the new well, are reported in Table 1; net power was 9.3 MW.

The simulated results are shown in Tables 2 and 3. The results are in agreement with the experimental data. The calculated net power is 9 MW.

Table 1. Experimental data (base case).

Node and well (Code)	Flow rate (t/h)	Flowing Pressure (bar)	NCG (-)	Wellhead Temperature (°C)
W11	9.1	5.6	4.24	150
W12	5.6	5.0	3.23	151
W26	26.8	5.4	5.39	228
W15	37.0	5.6	4.12	226
LAVPP2	5.0	5.6	0.00	15
PP2	79.0	4.0	4.37	158

Table 2. Simulated results in grid nodes (base case).

Node and Well (Code)	Flow rate (t/h)	Flowing Pressure (bar)	Wellhead Temp. (°C)	NCG (-)	Entalphy (kJ/kg)	Specific Volume (mc/kg)	Chloride (mg/l)
W11	9.2	5.13	153.9	0.042	2641	0.358	0.0
W12	5.6	4.61	150.0	0.032	2663	0.398	0.0
W26	26.2	5.94	229.0	0.054	2768	0.368	0.0
W15	37.1	6.01	226.7	0.041	2797	0.365	100.0
LAVPP2	5.0	5.39	206.6	0.043	2753	0.390	0.0
PP2	-83.1	4.48	151.5	0.045	2696	0.441	0.0
PP2c2	0.0	4.50	152.0	0.045	2696	0.439	0.0
W11d	0.0	5.13	153.9	0.042	2641	0.358	0.0
W12d	0.0	4.61	149.9	0.032	2663	0.398	0.0
W15d	0.0	6.01	226.7	0.041	2797	0.365	100.0
W26d	0.0	5.94	228.9	0.054	2768	0.368	0.0
CONC1	0.0	5.73	209.3	0.054	2728	0.366	0.0
N5	0.0	4.52	148.1	0.032	2659	0.404	0.0
N5A	0.0	4.52	148.8	0.039	2645	0.403	0.0
N7	0.0	5.94	226.1	0.041	2796	0.369	100.0
N8	0.0	5.41	197.0	0.047	2723	0.379	58.9
N8Bis	0.0	5.39	192.7	0.046	2715	0.376	54.6
N9	0.0	4.52	152.0	0.045	2696	0.438	0.0
N98	0.0	5.94	228.8	0.054	2768	0.368	0.0

Table 3. Simulation results in each branch (base case).

Pipeline Code Branch	Sub-	Extr1 (abbr)	Extr2 (abbr)	Flow rate (t/h)	Pressure loss (bar)	Average Temp. (°C)	NCG (-)	Entalphy 1 (kJ/kg)	Entalphy 2 (kJ/kg)	Specific volume (mc/kg)	Chloride (kg/h)
CN013	A85	W12	W12d	5.6	0.000	149.9	0.032	2663	2663	0.398	0.0
	B85	W12d	N5	5.6	0.086	149.0	0.032	2663	2659	0.401	0.0
	A85	W11	W11d	9.2	0.000	153.9	0.042	2641	2641	0.358	0.0
CN012	B85	W11d N5	N5A N5A	9.2 5.6	0.601 0.000	151.6 148.1	0.042 0.032	2641 2659	2636 2659	0.379 0.404	0.0 0.0
CN007	A85	N5A	N9	14.8	0.006	147.5	0.039	2645	2614	0.400	0.0
CN020	A85	W15 W15d	W15d N7	37.1 37.1	0.000 0.068	226.7 226.4	0.041 0.041	2797 2797	2797 2796	0.365 0.367	3.6 3.6
CN021	A85	N7	N8	37.1	0.537	217.5	0.041	2796	2762	0.379	3.6
LU077	A85	W26	W26d	26.2	0.000	228.9	0.054	2768	2768	0.368	0.0
		W26d	N98	26.2	0.002	228.8	0.054	2768	2768	0.368	0.0
LU252	A85	N98	CONC1	26.2	0.215	219.0	0.054	2768	2728	0.367	0.0
CN024	A85	CONC1	N8	26.2	0.321	194.8	0.054	2728	2668	0.364	0.0
CN022	A85	N8	N8Bis	63.3	0.018	197.0	0.047	2723	2723	0.380	3.6
	B85	LAVPP2	N8Bis	5.0	0.000	173.4	0.043	2753	2610	0.359	0.0
CN023	A85	N8Bis	N9	68.3	0.868	192.6	0.046	2715	2714	0.377	0.0
		N9	PP2c2	83.1	0.019	152.0	0.045	2696	2696	0.438	0.0
		PP2	PP2c2	-83.1	-0.025	151.5	0.045	2696	2696	0.440	0.0

Simulation of the W16 Wellbore Temperature Profile

On the basis of the initial production test, some simulations of dynamic temperature profile at various flowing pressure were made.

The uncertainty of these simulations is mainly due to the choice between isenthalpic (case A) or isothermal (case B) flow in the formation feeding the wellbore;

Case A

The assumption of an isenthalpic transformation is conservative. However, this assumption seamed to be the best one, as it reproduced the experimental well-head temperature data which were taken at short time. The model forecasted a saturation conditions all along the wellbore.

Case B

The gas/steam ratio at the end of the production test was 1.2% w/w, whereas the expected value is about 3-4%.

This difference is most likely due to the influence of the drilling fluids and so the transformation in the formations was assumed to be isothermal.

On this basis, the wellhead temperature is calculated to be 194°C (superheating 25°C) after only 8 days of production.

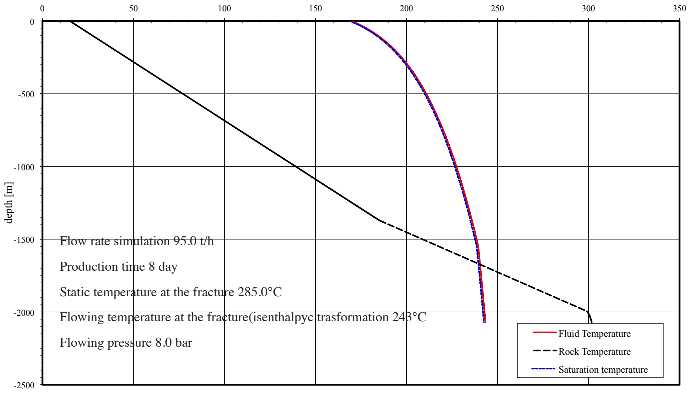

Figure 3. W16 wellbore temperature profile (case A).

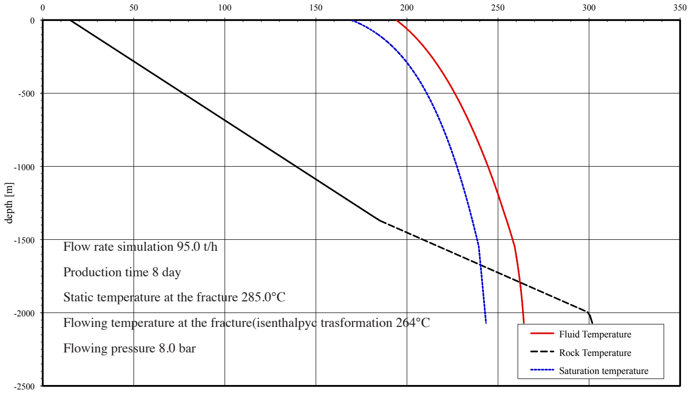

Figure 4. W16 wellbore temperature profile (case B).

The assumption of an isenthalpic transformation leads to the decision of fluid scrubbing in the wellbore.

This solution is particularly expensive, since it entails scrubbing also W15 well, which is producing from the same pad.

On the contrary, under the assumption of an isothermal transformation, scrubbing in the wellbore is not necessary. This assumption is also supported by the fact that W15 well has been producing a strongly superheated since the beginning.

Definition of a New Configuration of the Steam Pipeline Network to be Simulated

As a consequence of what said above, the following decisions were taken:

1. The fluid from W15 and W16 wells will be scrubbed by means of the scrubber already installed upstream the power station since the produced fluids are superheated.
2. The fluid produced by W26 well should be rerouted toward PP3 power plant since this well would bring the PP2 turbine flow-rate above its maximum limit.
3. For the same reason, the wells W11 and W12 should be rerouted toward PP1 power plant.

Simulation of the Network Feeding PP2 Power Plant at W16 Maximum Flowrate (95 t/h)

For the above scenario, the simulated results are shown in Tables 4 and 5.

The simulator forecasts a net power of 17 MW.

The increase, referred to base case, is 7 MW only for PP2 power plant.

Simulation of the PP2 Network at W16 Sustained Flow-Rate (70 t/h)

During the time required to connect W16 well to the existing pipeline, the well was kept discharging to its pad silencer in order to evaluate its temperature and flow-rate evolution. The result (Figure 5) confirms the expected temperature rise and the choice made regarding the location of the scrubbing unit.

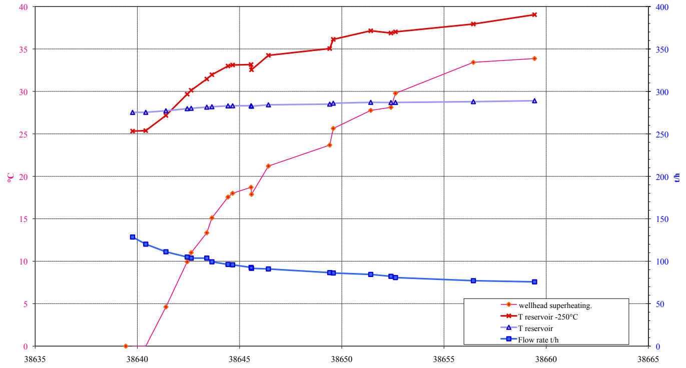

Figure 5. Evolution of W16 wellhead temperature and flow rate during production test.

Table 4. Simulated results in grid nodes (95 t/h case).

Node and well Code (abbr)	Flow rate (t/h)	Flowing Pressure (bar)	Wellhead Temp. (°C)	NCG (-)	Entalphy (kJ/kg)	Specific Volume (mc/kg)	Chloride (mg/l)
W15	36.0	12.75	244.8	0.041	2811	0.174	100.0
W16	92.9	12.91	227.0	0.040	2772	0.165	100.0
LAVPP2	7.9	9.43	216.8	0.041	2762	0.224	0.0
PP2	-136.7	7.18	166.0	0.040	2766	0.295	0.0
PP2c2	0.0	7.19	166.0	0.040	2766	0.294	0.0
W15d	0.0	12.75	244.8	0.041	2811	0.174	100.0
W16d	0.0	12.91	227.0	0.040	2772	0.165	100.0
N7	0.0	12.71	231.4	0.040	2782	0.169	100.0
N8	0.0	9.43	220.8	0.040	2772	0.226	100.0
N8Bis	0.0	9.38	218.1	0.040	2766	0.226	94.3
N9	0.0	7.23	213.4	0.040	2766	0.293	0.0

Table 5. Simulation results in each branch (95 t/h case).

Pipeline Code Branch	Sub	Extr1 (abbr)	Extr2 (abbr)	Flow rate (t/h)	Pressure loss (bar)	Average Temp. (°C)	NCG (-)	Entalphy 1 (kJ/kg)	Entalphy 2 (kJ/kg)	Specific volume (mc/kg)	Chloride (kg/h)
CN020	A85	W15	W15d	36.0	0.000	244.8	0.041	2811	2811	0.174	3.4
CN027	A85	W16	W16d	92.9	0.000	227.0	0.040	2772	2772	0.165	8.9
CN020	A85	W16d	N7	92.9	0.192	226.8	0.040	2772	2771	0.166	8.9
	A85	W15d	N7	36.0	0.030	244.6	0.041	2811	2810	0.174	3.4
CN021	A85	N7	N8	128.8	3.288	226.2	0.040	2782	2772	0.193	12.4
CN022	A85	N8	N8Bis	128.8	0.044	220.7	0.040	2772	2772	0.226	12.4
	B85	LAVW11	N8Bis	7.9	0.044	197.0	0.041	2762	2671	0.213	0.0
CN023	A85	N8Bis	N9	136.7	2.157	217.7	0.040	2766	2766	0.229	0.0
		N9	PP2c2	136.7	0.034	166.0	0.040	2766	2766	0.294	0.0
		PP2	PP2c2	-136.7	-0.013	166.0	0.040	2766	2766	0.294	0.0

The well W16 was connected in November 2005. By then, the flow-rate had declined to 70 t/h and, thereby, the previous pipeline network simulation was not valid anymore. In fact, the decline of W16 well made the utilization of the wells W11 and W12 in PP2 power plant possible. Only W26 well had to be rerouted to PP3 power plant.

The simulated results are reported in Tables 6 and 7. The relevant power is 16.4 MW.

The measured data are reported in Table 8.

Table 6. Simulated results in grid nodes (70 t/h case).

Node and well Code (abbr)	Flow rate (t/h)	Flowing Pressure (bar)	Wellhead Temp. (°C)	NCG (-)	Entalphy (kJ/kg)	Specific Volume (mc/kg)	Chloride (mg/l)
W11	13.5	8.03	190.4	0.042	2705	0.247	0.0
W12	7.6	7.26	195.4	0.032	2747	0.280	0.0
W15	37.2	11.46	233.8	0.041	2791	0.190	100.0
W16	67.7	11.54	217.3	0.040	2755	0.181	100.0
LAVPP2	7.9	9.09	217.3	0.041	2765	0.233	0.0
PP2	-133.8	7.10	166.0	0.040	2740	0.289	0.0
PP2c2	0.0	7.11	166.5	0.040	2740	0.289	0.0
W11d	0.0	8.03	190.4	0.042	2705	0.247	0.0
W12d	0.0	7.26	195.3	0.032	2747	0.280	0.0
W15d	0.0	11.46	233.8	0.041	2791	0.190	100.0
W16d	0.0	11.54	217.3	0.040	2755	0.181	100.0
N5	0.0	7.15	186.4	0.042	2701	0.276	0.0
N5A	0.0	7.15	189.1	0.039	2717	0.279	0.0
N7	0.0	11.43	222.7	0.040	2767	0.185	100.0
N8	0.0	9.12	212.7	0.040	2755	0.229	100.0
N8Bis	0.0	9.09	210.1	0.040	2749	0.229	93.0
N9	0.0	7.14	166.5	0.040	2741	0.288	0.0

Table 8. Experimental data (70 t/h case).

Node and well (Code)	Flow rate (t/h)	Flowing Pressure (bar)	NCG (-)	Wellhead Temp. (°C)
W11	13.5	7.50	4.24	189
W12	7.6	7.51	3.23	196
W15	37.3	11.00	4.12	233
W16	67.7	11.38	4.00	217
LAVPP2	5.0	5.00	0.00	15
PP2	128.0	7.06	4.37	165

The measured net power was 16 MW in agreement with the simulation results.

The simulation showed also a high pressure loss (2.3 barA) between the nodes N7 and N8 (pipe CN021).

The apparent reason for this anomaly was the flow-rate increase from 37 to 105 t/h in this branch; as a consequence, the existing pipeline (450 mm) resulted undersized. In the new configuration the optimum economic diameter is 800 mm and, thus, the decision was taken to substitute this critical branch.

Due to rerouting W26 to PP3 power plant, this power plant gained 1.5 MW.

Table 7. Simulation results in each branch (70 t/h case).

Pipeline Code Branch	Sub	Extr1 (abbr)	Extr2 (abbr)	Flow rate (t/h)	Pressure loss (bar)	Average Temp. (°C)	NCG (-)	Entalphy 1 (kJ/kg)	Entalphy 2 (kJ/kg)	Specific volume (mc/kg)	Chloride (kg/h)
CN013	A85	W12	W12d	7.6	0.00	195.3	0.032	2747	2747	0.280	0.0
	B85	W12d	N5A	7.6	0.11	194.6	0.032	2747	2745	0.282	0.0
CN012	A85	W11	W11d	13.5	0.00	190.4	0.042	2705	2705	0.247	0.0
	B85	W11d	N5	13.5	0.88	188.4	0.042	2705	2701	0.261	0.0
		N5	N5A	13.5	0.00	186.4	0.042	2701	2701	0.276	0.0
CN007	A85	N5A	N9	21.1	0.01	184.4	0.039	2717	2695	0.276	0.0
CN020	A85	W15	W15d	37.2	0.00	233.8	0.041	2791	2791	0.190	3.6
CN027	A85	W16	W16d	67.7	0.00	217.3	0.040	2755	2755	0.181	6.5
CN020	A85	W16d	N7	67.7	0.11	217.1	0.040	2755	2755	0.182	6.5
	A85	W15d	N7	37.2	0.04	233.6	0.041	2791	2790	0.190	3.6
CN021	A85	N7	N8	104.9	2.31	217.7	0.040	2767	2755	0.205	10.1
CN022	A85	N8	N8Bis	104.9	0.03	212.6	0.040	2755	2755	0.230	10.1
	B85	LAVPP2	N8Bis	7.9	0.00	197.5	0.041	2765	2674	0.221	0.0
CN023	A85	N8Bis	N9	112.8	1.95	209.8	0.040	2749	2749	0.231	0.0
		N9	PP2c2	133.8	0.03	166.5	0.040	2741	2740	0.289	0.0
		PP2	PP2c2	-133.8	-0.01	166.0	0.040	2740	2740	0.289	0.0

Conclusions

- Total production increased by 8 MW
- The results confirmed the model previsions.
- This numerical simulator proved to be a reliable tool for deciding the best network layout and pointing out possible critical points.

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