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Using GIS for Practical Geothermal Applications: an Inventory of the Thermal Insulation Condition of the Cerro Prieto Geothermal Field Pipeline Transportation Network

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ABSTRACT

The Cerro Prieto geothermal field (CPGF) steam production and transportation system includes 165 producing wells and more than 160 kilometers of pipes with diameters ranging from 8” to 48” from which 92 km belong to the High Pressure (HP) steam pipeline network, 48 km to the Low Pressure (LP) steam pipeline network and 26 km to mixture pipelines (M). Originally, all pipes are thermally insulated with a mineral wool or fiber glass layer and an external aluminum or iron cover. However, in some parts of the network this insulation shows nowadays different grades of damage. As part of a comprehensive study which included the assessment of the heat losses throughout the CPGF pipeline network, it was necessary to inventory the current insulation condition, for which four different insulation qualities were defined: (A) new or complete, with metallic cover, (B) good or without metallic cover, (C) regular or slightly damaged and (D) totally destroyed or absent. The inventory was surveyed in the field and all data was implemented into a Geographical Information System (GIS). This tool successfully helped to easily identify those parts of the network where heat losses may be higher, and facilitated the precise quantification of the length corresponding to each insulation quality for each pipeline network (HP, LP, M) and to each pipe diameter. According to the inventory results, about 80% of the total length of the three networks has thermal insulations belonging to A and B qualities, while the remaining 20% showed insulations with qualities C and D. While the results of this work were eventually used for heat loss calculations of the entire transportation network, the methodology employed and generated datasets constitute a basis for developing several practical GIS applications related with the design, operation and maintenance in the CPGF and other geothermal steam fields.

1. INTRODUCTION

A Geographic Information System (GIS) is a computer system that allows the capture, maintenance, analysis, integration and deployment of any data relating to a location or a map. In the sphere of subsurface energy resources, e.g. oil or geothermal energy, GIS technology has an enormous potential for use since most of the data and decisions associated with exploration, exploitation, collection, transport and management of these resources invariably involve a geographical component. In oil industry, GIS has been widely used and proved to be an invaluable tool for the storage, graphic display, correlation, analysis and sharing of data, as well as decision-making in the different stages that constitutes this complex industry, from geological exploration to distribution and marketing (Gaddy, 2003; Acharya, 2003).

As to the geothermal field concerned, despite having various similarities with the oil industry, GIS utilization has mainly been focused on applications related to Geosciences. Thus, the literature often relapse on GIS being used as a tool for the generation of spatial databases, automated mapping systems, creation of knowledge-based models for the identification of areas with geothermal potential as well as the selection of sites for drilling wells, power plants and another geothermal facilities (Prol-Ledesma, 2000; Martinez-Estrella et al., 2005; Lara-Cuervo, 2006; Noorollahi et al., 2007; Olivar, 2007; Yousefi and Ehara, 2008; García-Estrada et al., 2008, Carranza et al., 2008). Some few different applications are reported in the open literature, e.g. support for the interpretation of the geological structure in geothermal areas; display and analysis of isotopic data; storage and display of digital images of cores and associated data (Nash 1999; Nash y Adams; 2001).

Despite being a relatively recent technology, the use of GIS in different areas of knowledge and industries has generated an important set of concepts, methodologies and database models, as well as documented case studies (e.g. the oil industry), that could be adopted, adapted and applied to geothermal energy, not only in aspects related to the exploration and development of new sites, but also as a support for exploitation and management of assets in geothermal fields under operation.

A preliminary digital data model applied to geothermal databases was proposed by Setijadji et al. (2005) and its implementation was exemplified by three case studies applied to geothermal fields on the island of Java, Indonesia, using ArcGIS software platform. Although in his work this author emphasizes again in geological data, the use of concepts and methodologies designed for other applications, not traditionally used in geothermal energy, as the use of system of referencing linear for managing geothermal well data could be seen as a novelty.

This work presents an example of practical application of GIS applied to the Cerro Prieto geothermal field steam pipeline transportation network, Mexico. The application consisted in an inventory of the physical condition that keeps the thermal insulation of the pipes that make up the pipeline network carrying the geothermal fluids from wells to geothermal plants. The results of this inventory allowed us to generate data which were eventually used in the overall heat loss calculations from piping towards the environment (Ovando-Castelar et al., these proceedings) as well as in a technical-economic study aimed to replace damaged insulation sections throughout the CPGF steam transportation network.

2. BACKGROUND

The Cerro Prieto geothermal field (CPGF) is the largest liquid-dominated field in the world (720 MWe) and consists of four production areas, each one with a power station, progressively called Cerro Prieto One (CP1) to Cerro Prieto Four (CP4). Up to 2009, the CPGF fluid production and transportation system was constituted by a network of 165 producing wells and about 170 km of pipes with diameters ranging from 8 to 48". These pipes are connected forming different networked branches. CP2, CP3 and CP4 steam fields exist parallel branches of high pressure (HP) and low pressure (LP). This denomination comes from the type of separation (primary or HP and secondary or low pressure) that takes place in the wells. Originally, all the piping is thermally insulated with a 2" thick layer of mineral wool- or glass fiber-based material, and an outer cover of aluminum or iron. Over the years, in some parts of the network, this insulation has been undergoing varying degrees of deterioration.

In 2006, Garcia et al. performed a modeling and numerical flow simulations of the entire CPGF steam pipeline network in which a very important result was the detection of various areas of opportunity to improve the operation of the network and increase the energy utilization of fluid extracted from the wells. It was found that a major source of energy loss during transport of fluids from wells to the generating units was associated to the heat losses due to wear or lack of the thermal insulation in some portions of the network.

Later, as part of a comprehensive study for the assessment of the energy efficiency of the CPGF production and fluid transport system (Garcia et al., 2009), an analysis and interpretation of the main sources of energy loss throughout the network was carried out. In this analysis, a quantification of the heat losses from the pipes that make up the transport network to the environment, based on the physical condition that the insulation holds, was included. The calculation of these heat losses required determining for each single pipeline section its length and diameter, the difference in temperature between fluid and the outside and the overall heat transfer coefficient (U).

In a general way, heat losses are defined by the following equation:

$$Q = U\ A\ \Delta T \tag{1}$$

Where U, A, ΔT are the overall heat transfer coefficient, the pipe section area defined by πDL and the temperature difference between the pipe surface and the air, respectively.

Heat losses are determined by the area of the pipe section and the physical state of the insulation. The pipe section area is directly proportional to length L and diameter D so that it was required to know the length L related to each pipe diameter D, for each insulation type and condition. In general, for a given insulation condition the larger the pipe diameter, the larger the pipe area, and therefore, the greater the heat loss. Thus, in order to calculate the overall heat losses it was needed to inventory the physical condition of the thermal insulation throughout the CPGF pipeline fluid transportation network.

3. METHODOLOGY

Since in the CPGF pipeline network the thermal insulation condition varies from new to absent (bare pipe) with various degrees of deterioration, for the inventory it was determined to classify the insulation condition into four different levels of quality, as shown in Table 1. For a better illustration, representative examples of each insulation condition are shown in Figure 1.

Table 1: Classification of pipeline thermal insulations based on its physical

Condition	Code	Color_code
New or complete, with metallic cover	A	
Good or without metallic cover, barely deformed	B	
Regular or visibly damaged	C	
Bad or absent, completely destroyed	D	

3.1 Field inventorying

For the inventory both steam and mixture lines were included. Ducts out of service were excluded. Classification of pipe insulation condition was determined by *on-site* visual inspection and all the data registered in *hard-copy* pipeline network maps supplied by the steam field operator. This method, although seems to be somewhat rudimentary, allows us, besides getting all insulation condition data, to detect several inconsistencies and outdates in the hard-copy base maps. The inventory was complemented with a photographic record of every pipe section for eventual consultations.

2.2 Data Processing

A GIS was proposed to be used as an effective tool to facilitate the management and analysis of all inventory data according to our needs. Geothermal infrastructure can be represented and modeled within GIS as a set of vectors organized in layers, as CAD software does. Prior to load inventory data into GIS, it was needed to do some corrective work to the original CPGF pipeline network CAD files from which hard-copy maps used in the field work were printed. Main "pre-processing" tasks included:

- Updating the original CAD base-map by including new or missing information and correcting inaccuracies;

- Converting lines into polylines since most of lines were drawn as multi-part simple lines, so that it was necessary to draw all pipelines as single, continuous lines;
- Organizing data into layers: polylines were grouped according to the operational system of pipelines (HP-, LP- or M-pipelines) and its hierarchy structure (branch or main collector, sub-collector, interconnection, one-well mixture line or steam line); polylines representing pipelines out of operation were grouped into a single layer;
- Cleaning: polylines representing pipes no longer existing in the steam field were eliminated.

Figure 1: Representative examples of each insulation condition as defined in Table 1.

Once all the proper corrections were done to CAD base-map, the interest layers were imported into ESRI´s ArcGIS software. After that, each single polyline was assigned a unique identification code (ID). This ID was defined such that indicates for every pipeline its operational hierarchical group, the number/name (assigned for the field operator) of the well supplying the fluid, and the system which every pipeline feeds to: high- or low-pressure steam, or well mixture (Table 2). In the case of main branches since branch number is repeated in the four CPGF field sectors, it was needed to specify to which sector each branch belongs to.

Table 2. Main criteria and corresponding codes used for identifying pipe segments

Steam field sector	System network		Pipeline Operational Hierarchy	
CP1	AP	High-pressure (HP) steam	R	Branch or main collector (Ramal, in Spanish)
CP2			SC	Sub-collector
CP3	BP	Low-pressure (LP) steam	IC	Interconnection pipeline
			V	Single-well steam pipe
CP4	M	Mixture	M	Single-well mixture line

The pipelines were modeled using the linear referencing system (LRS). This system is suitable for the management of data related to objects that has a linear nature in the real world, e.g. roads, railways, power transmission lines, rivers, pipelines, wells, etc. (ESRI, 2001, 2003). In LRS each line path is referred to as the linear reference or route. Routes are special polylines having in its geometry x, y, z, and m (*measure* length) dimensions. *Measures* are continuous values which typically increase in the motion direction of fluids (or well, other goods). The LRS is designed so that if a segment in a route is changed, only the distance values in the modified segment need to be updated.

The CPGF pipeline network constitutes basically a horizontal network so that measure values were set based on the distance or cumulative length from the beginning of each pipeline path in the base map. This point corresponds to the location of the ball valve after well separators. Since the original digitizing direction (CAD) of some polylines was contrary to the movement of the geothermal fluids, it was necessary to reverse the digitization of these polylines so that the first pair of coordinates of these polylines should become the last and vice versa, and then route measure values were restored.

The LRS enables to locate all features and events along the paths (route events) and these can be determined dynamically as long as the path ID and the measure distance along the path are provided. This process is known as Dynamic Segmentation. To locate any device or occurrence along a route, the LRS requires the creation of tables called event tables, which contain information of route locations and attributes of the events. Among these attributes, each event must invariably include a Route ID and a position (measure) counted from the beginning of the route. For linear events, two positions (initial and final) are required.

Table 3 shows an example of event table applied to our study case. In the event table, it is seen that Well 301 steam pipe (V301-AP, 257 m long) has only insulation type C, while the insulation condition in Well 102 steam pipe (V102-AP, 200.97 m long) is very heterogeneous. Initial and final values are distances, counted from the origin, where insulation condition changes. For each duct, the final m value of the last insulation section, represent the maximum length of the pipeline.

Table 3. Thermal insulation condition event table in MS Excel worksheet

Clave_ducto	Tipo_ducto	Sistema	Condición_aislante	Tramo_ini	Tramo_fin
V105-AP	Vaporducto	AP	B	0.000	169.701
V107-AP	Vaporducto	AP	B	0.000	143.476
V107-AP	Vaporducto	AP	D	143.476	145.476
V301-AP	Vaporducto	AP	C	0.000	257.401
V302-AP	Vaporducto	AP	B	0.000	114.123
VM19A-AP	Vaporducto	AP	C	0.000	156.703
VM19A-AP	Vaporducto	AP	B	156.703	226.102
VM19A-AP	Vaporducto	AP	C	226.102	291.727
VM20-AP	Vaporducto	AP	C	0.000	115.294
VM30-AP	Vaporducto	AP	B	0.000	141.123
VE2-AP	Vaporducto	AP	C	0.000	277.858
V102-AP	Vaporducto	AP	B	0.000	69.002
V102-AP	Vaporducto	AP	A	69.002	117.006
V102-AP	Vaporducto	AP	D	117.006	118.006
V102-AP	Vaporducto	AP	B	118.006	200.970
V605-AP	Vaporducto	AP	B	0.000	134.038
V605-AP	Vaporducto	AP	D	134.038	138.038

Initial and final measure values of every insulation section were obtained by transferring manually all recorded inventory data from the hard-copy maps and field annotations. This was done by adding new vertices to the route lines at the point positions where a change in the insulation condition was recorded. Once new vertices were all input, corresponding route measure values were restored.

2.3 Insulation condition maps

In LRS, the process that allows to graphically visualizing events that are not modeled with a "real" geometry is called Dynamic Segmentation (Brennan, 2002; Cadkin and Brennan, 2002). Figures 2 and 3 illustrate this process.

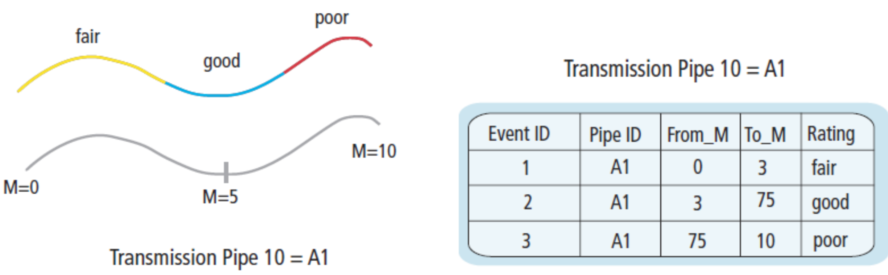

Figure 2. Linear referencing and dynamic segmentation (from Cadkin, 2002)

In Figure 4, an example of the graphical display of insulation condition events is shown. There, the event table containing insulation condition data of the Branch 1 of CP2 steam field (CP2-R1-AP) is linked to the CPGF pipeline route feature class through the Route_ID If any attribute in the event table is changed the map is updated dynamically. This constitutes a great advantage over representing insulation condition as simple lines segments with static geometry.

This way, maps of the insulation condition maps were generated for each CPGF piping system (HP-steam network, LP-steam network and mixture pipes) which are shown in figures 4 to 6. Same procedure was used to generate the corresponding pipe diameter maps (figures 7 to 9).

2.4 Map Analysis

Once insulation condition and pipe diameter maps were drawn, GIS geoprocessing tools were used in order to draw pipeline sections corresponding to the spatial intersection of each insulation condition and each pipe diameter for each transportation system

(HP, LP, M). In LRS, the overlapping of geometries generated from two tables of linear events (insulation condition and pipe diameter) is called *overlay line-on-line* and gives, as a result, a new linear events table that can whether the intersection or logical connection of input tables. Taking into account the existence of four categories of insulation, and a wide variety of pipe diameters in the pipeline network (8 to 48”), it can be realized the amount of intersection operations needed to be performed.

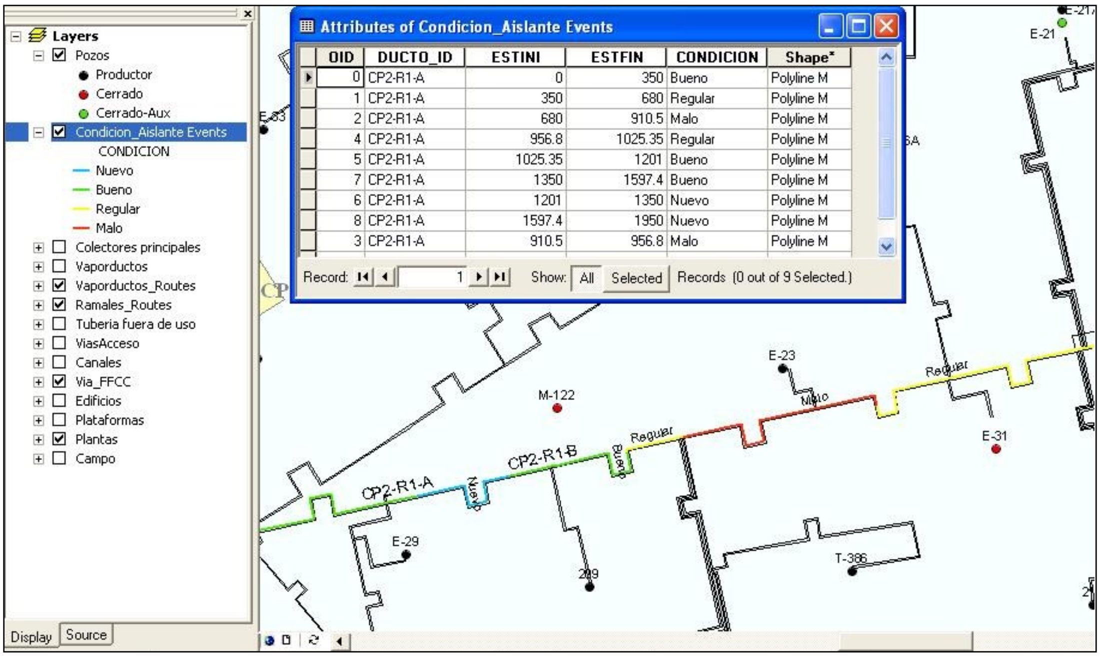

Figure 3. Dynamic segmentation: from the corresponding event table, insulation condition is displayed on the route CP2-R1-AP (Branch-2 of CP2, HP-steam system).

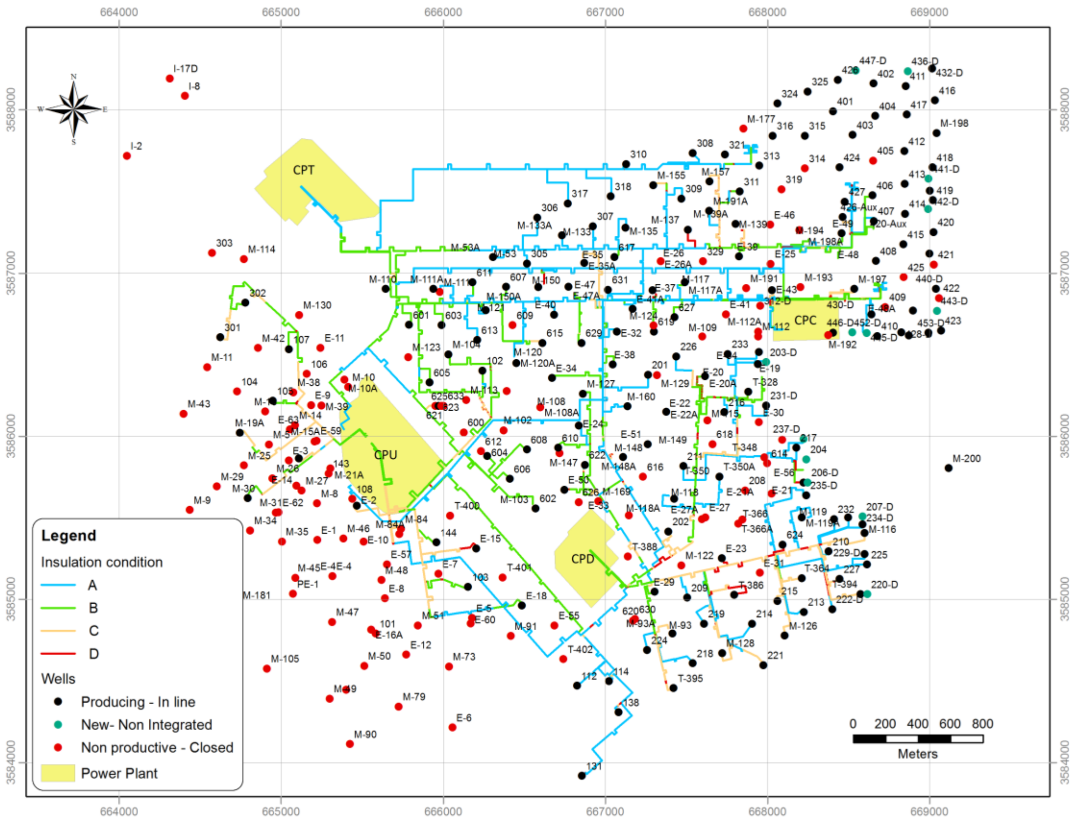

Figure 4. Insulation condition map of the HP-steam pipeline network

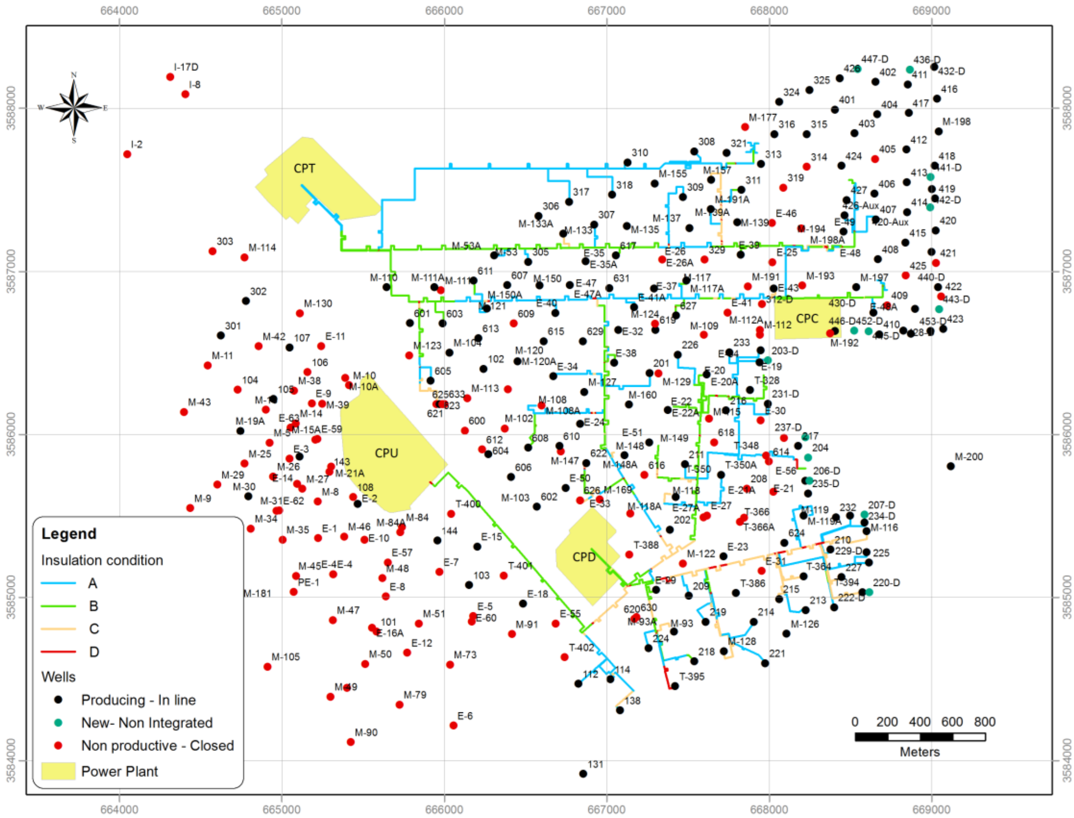

Figure 5. Insulation condition map of the LP-steam pipeline network

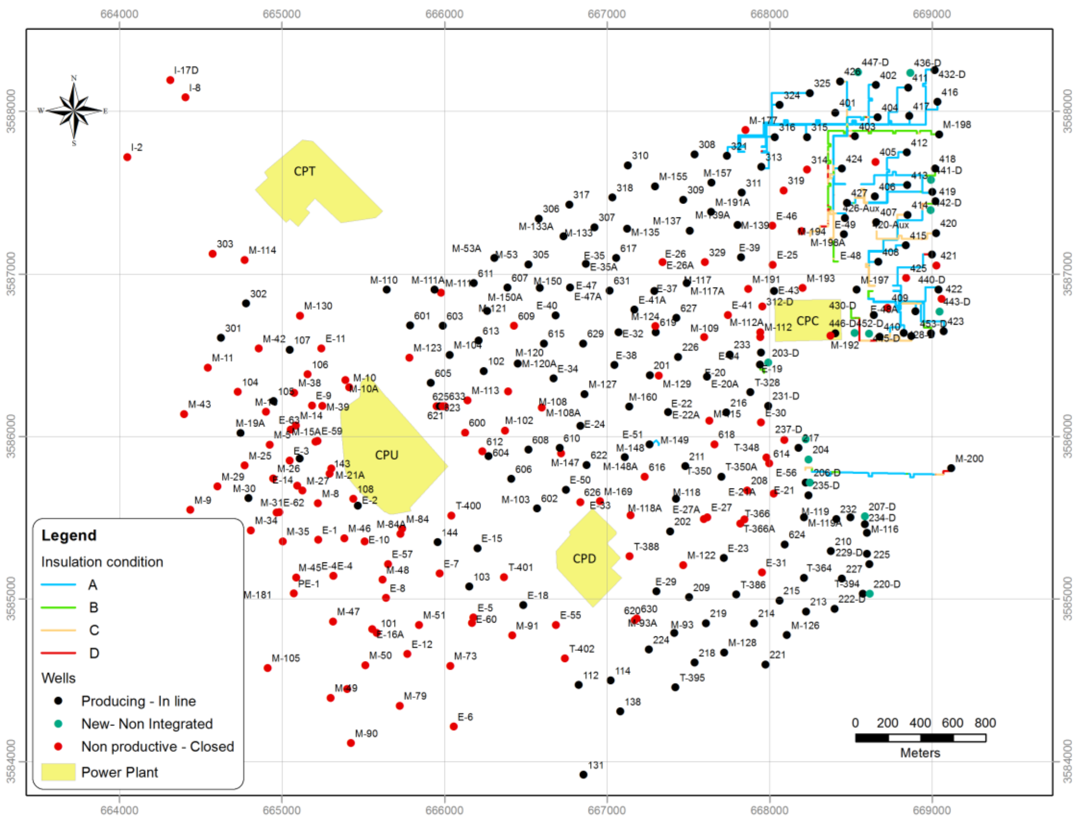

Figure 6. Insulation condition map of mixture pipelines

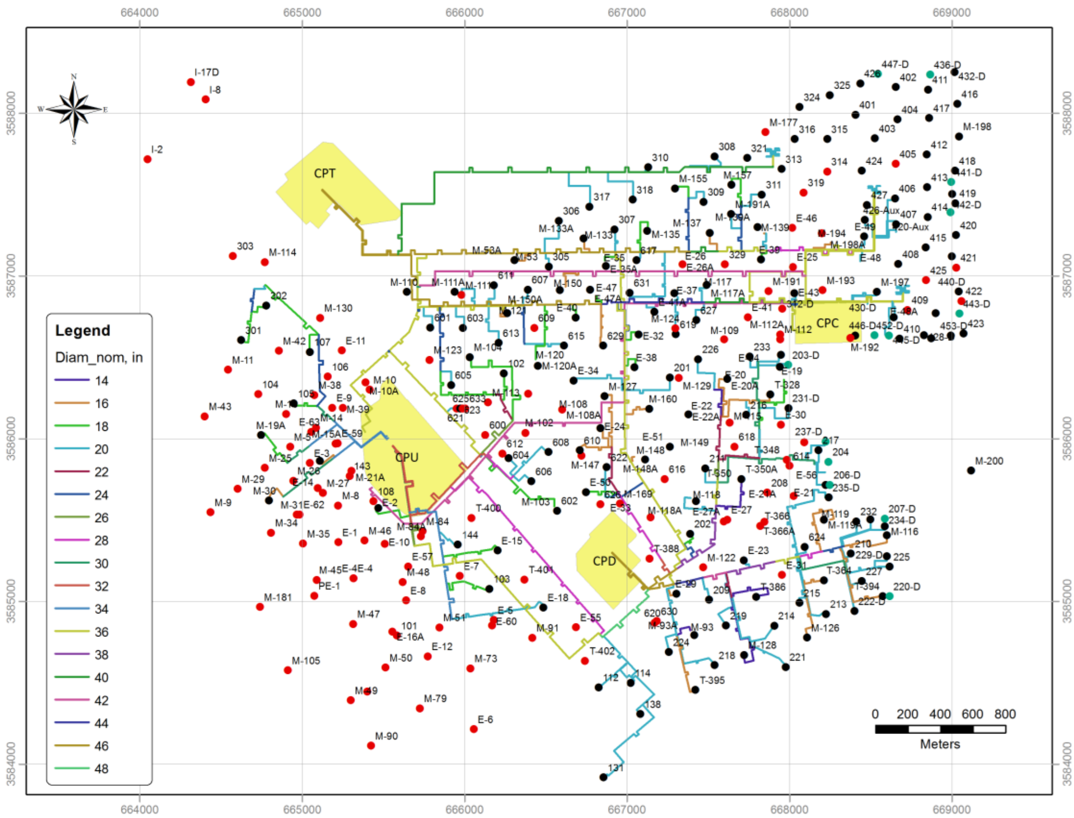

Figure 7. Pipe diameter map of the HP-steam pipeline network

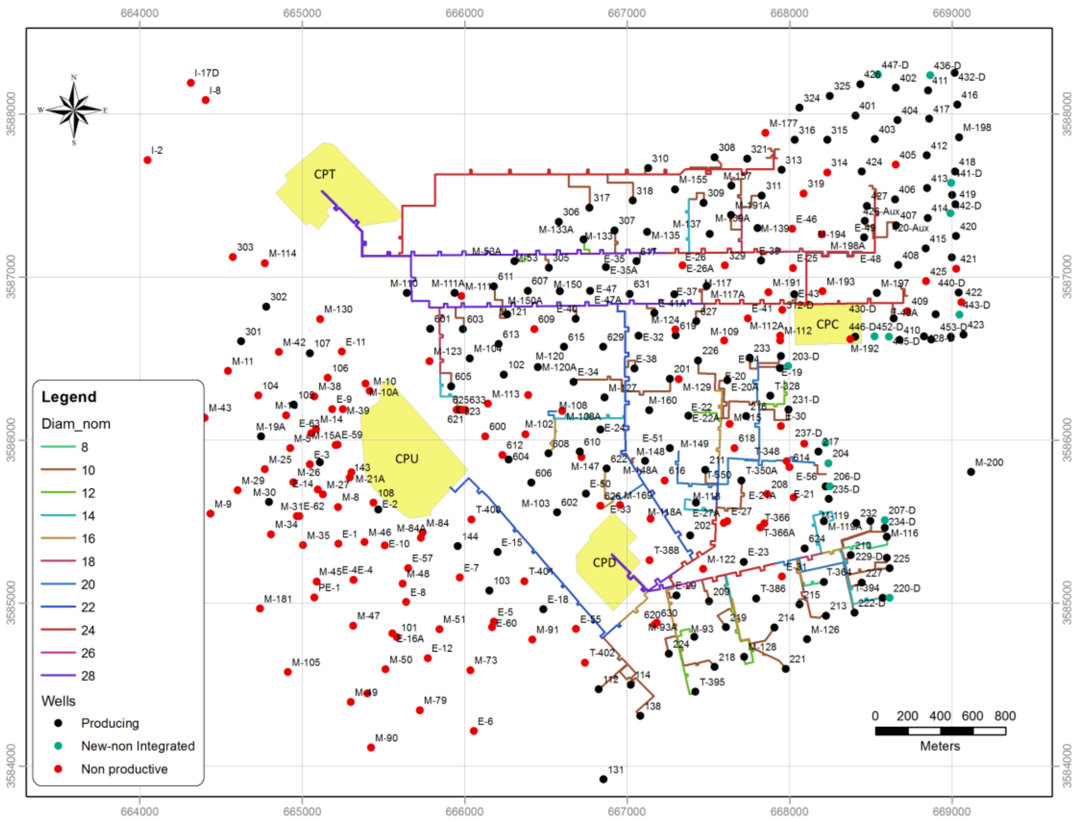

Figure 8. Pipe diameter map of the LP-steam pipeline network

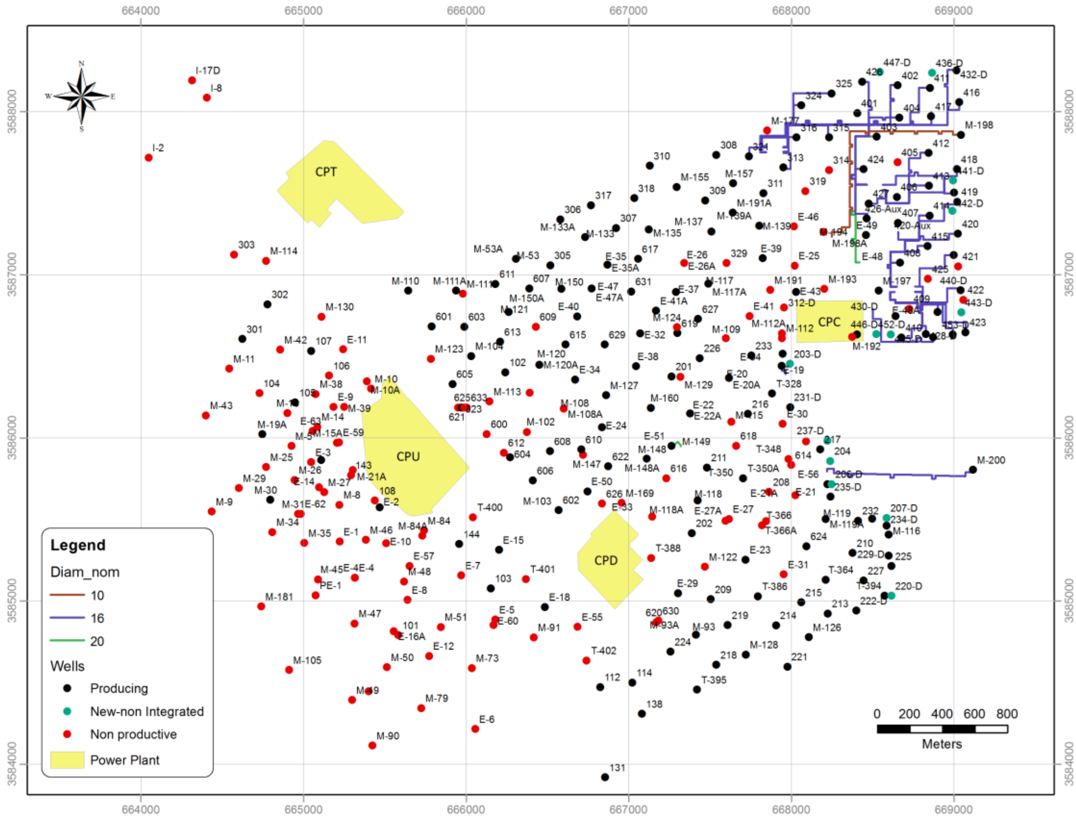

Figure 9. Mixture-pipelines diameter map

3. RESULTS

The final results of the quantification are given in tables 4 to 8. Table 4 presents a summary of the pipe lengths for each production system (HP, LP, and M) and the percentage which occupies each in relation to the total length.

Table 4. Total lengths of each CPGF pipeline transportation network by system

System	Length (m)	%
HP (AP) steam	92078.906	55.56
LP (BP) steam	47622.712	28.74
Mixture	26017.787	15.70
TOTAL CP	**165719.405**	**100.00**

Table 5 shows the summation of lengths corresponding to each insulation condition type in each of the three production systems. The detailed results of the length of each condition of insulation for each diameter of high pressure network are shown in table 6, while table 7 shows the statistics of low pressure piping system. Table 8 shows the statistics for the of mixture-pipes network. Diameters are expressed in inches.

According to the inventory results, for the three systems or transport networks, HP-, LP, and M-pipes, there is a coincidence in the proportion of the length of those pipes considered to have insulations in good condition (A and B), and insulations with regular or bad condition (C and D). Insulations classified as new or in good condition represent about 80-82% of the total length, while the remaining 18-20% of the total length has insulations in regular or bad condition. Here is where the greater heat losses would be expected to occur.

On the other hand, the proportion of mixture pipes having insulations type A is notably higher than those pipes carrying only steam. As expected, insulation condition in those ducts having longer operation time present further deterioration. This is the case of the pipeline networks of CPU and CPD (Branch-1) steam fields.

Table 5. Total length of the thermal insulation condition sections for each CPGF pipeline transportation system

System	Insulation Condition	Length (m)	%
HP (AP)-Steam	A	44197.763	48.00
	B	30283.234	32.89
	C	14958.022	16.24
	D	2639.884	2.87
	Total	**92078.903**	**100.00**
LP (BP)-Steam	A	23041.470	48.38
	B	16091.515	33.79
	C	7384.856	15.51
	D	1104.871	2.32
	Total	**47622.712**	**100.00**
Mixture	A	18612.723	71.54
	B	2329.807	8.95
	C	4470.710	17.18
	D	604.546	2.32
	Total	**26017.787**	**100.00**
	TOTAL CP	**165719.402**	

Table 6. Calculated length of the different thermal insulation condition sections for the HP steam pipeline transportation system

					Insulation Condition (length, m)				
System	**Pipe Hierarchy**	**Nominal Diameter (in)**	**Total Length (m)**	**%**	**A**	**B**	**C**	**D**	**Subtotal**
HP (AP)-Steam	Single-well pipe	14.000	1549.337	4.510	370.821	0.000	905.486	273.030	*1549.337*
		16.000	5945.647	17.308	1333.115	1965.370	2195.190	451.972	*5945.647*
		18.000	6515.226	18.966	1038.569	3536.787	1726.800	213.071	*6515.226*
		20.000	19711.993	57.383	13002.164	4262.862	1697.738	749.226	*19711.990*
		22.000	306.673	0.893	0.000	0.000	306.673	0.000	*306.673*
		24.000	322.921	0.940	320.921	0.000	0.000	2.000	*322.921*
		SubTotal	***34351.797***	***100.000***	***16065.590***	***9765.019***	***6831.887***	***1689.298***	***34351.794***
	Subcollector	14.000	244.536	2.586	0.000	244.536	0.000	0.000	*244.536*
		18.000	548.773	5.802	0.000	411.920	127.839	9.014	*548.773*
		20.000	2066.807	21.853	908.304	657.231	501.271	0.000	*2066.807*
		22.000	531.760	5.623	0.000	518.848	0.912	12.000	*531.760*
		24.000	2076.375	21.954	442.489	778.602	822.294	32.991	*2076.375*
		28.000	877.076	9.274	225.942	462.704	188.431	0.000	*877.076*
		30.000	2111.725	22.328	2098.917	12.808	0.000	0.000	*2111.725*
		32.000	214.929	2.273	116.805	97.540	0.585	0.000	*214.929*
		36.000	785.649	8.307	0.000	785.649	0.000	0.000	*785.649*
		SubTotal	***9457.632***	***100.000***	***3792.457***	***3969.839***	***1641.331***	***54.005***	***9457.632***
	Branch or Main Collector	18.000	608.236	1.260	53.514	542.722	0.000	12.000	*608.236*
		22.000	570.610	1.182	0.000	341.075	154.115	75.420	*570.610*
		24.000	941.873	1.951	159.685	512.354	188.397	81.437	*941.873*
		26.000	989.110	2.049	0.000	379.715	573.932	35.463	*989.110*
		28.000	2914.242	6.037	23.790	2323.340	476.790871	90.322	*2914.242*
		30.000	1397.226	2.895	24.671	603.222	749.334	20.000	*1397.226*
		32.000	2021.966	4.189	0.000	1419.936	595.030	7.000	*2021.966*
		34.000	2770.503	5.740	58.508	951.712	1758.694	1.589	*2770.503*
		36.000	14093.617	29.198	7669.791	5364.814	876.185	182.827	*14093.617*
		38.000	1092.176	2.263	0.000	247.670	526.348	318.158	*1092.176*
		40.000	4302.011	8.912	4110.236	164.242	17.966	9.567	*4302.011*
		42.000	7588.057	15.720	7342.491	47.061	198.505	0.000	*7588.057*
		44.000	1035.320	2.145	713.755	72.621	248.944	0.000	*1035.320*
		46.000	7381.699	15.293	3648.470	3577.891	120.563	34.774	*7381.699*
		48.000	562.830	1.166	534.806	0.000	0.000	28.024	*562.830*
		SubTotal	***48269.477***	***100.000***	***24339.716***	***16548.376***	***6484.804***	***896.581***	***48269.477***
		Totals	**92078.906**		**44197.763**	**30283.234**	**14958.022**	**2639.884**	**92078.903**

4. CONCLUSIONS

This paper described the methodology and results of an inventory of the physical condition that holds the thermal insulations of the pipes that constitute the CPGF fluid transportation network. The inventory was carried out in the field considering four different categories of insulation quality according to their degree of deterioration: (A) new or complete with metallic cover, (B) good or without metallic protection, (C) regular or damaged and (D) absent or completely destroyed.

All the data were integrated into a GIS in order to facilitate the management, deployment and analysis of the inventory information. The linear referencing system (LRS) was employed to model the pipeline network and condition of thermal insulations, allowing a very detailed quantification of the length belonging to each insulation category for each diameter of existing pipe in the network of pipelines, taking into account the system where each pipeline operates: HP- or LP- steam line, or well, mixture line. From the authors' point of view, it is believed that achieving this result without GIS tools would have been a very tough task.

Table 7. Calculated length of the different thermal insulation condition sections for the LP steam pipeline transportation system

					Insulation Condition (length, m)				
System	**Pipe Hierarchy**	**Nominal Diameter (in)**	**Total Length (m)**	**%**	**A**	**B**	**C**	**D**	**Subtotal**
HP (AP)-Steam	Single-well pipe	14.000	1549.337	4.510	370.821	0.000	905.486	273.030	*1549.337*
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		22.000	306.673	0.893	0.000	0.000	306.673	0.000	*306.673*
		24.000	322.921	0.940	320.921	0.000	0.000	2.000	*322.921*
		SubTotal	***34351.797***	***100.000***	***16065.590***	***9765.019***	***6831.887***	***1689.298***	***34351.794***
	Subcollector	14.000	244.536	2.586	0.000	244.536	0.000	0.000	*244.536*
		18.000	548.773	5.802	0.000	411.920	127.839	9.014	*548.773*
		20.000	2066.807	21.853	908.304	657.231	501.271	0.000	*2066.807*
		22.000	531.760	5.623	0.000	518.848	0.912	12.000	*531.760*
		24.000	2076.375	21.954	442.489	778.602	822.294	32.991	*2076.375*
		28.000	877.076	9.274	225.942	462.704	188.431	0.000	*877.076*
		30.000	2111.725	22.328	2098.917	12.808	0.000	0.000	*2111.725*
		32.000	214.929	2.273	116.805	97.540	0.585	0.000	*214.929*
		36.000	785.649	8.307	0.000	785.649	0.000	0.000	*785.649*
		SubTotal	***9457.632***	***100.000***	***3792.457***	***3969.839***	***1641.331***	***54.005***	***9457.632***
	Branch or Main Collector	18.000	608.236	1.260	53.514	542.722	0.000	12.000	*608.236*
		22.000	570.610	1.182	0.000	341.075	154.115	75.420	*570.610*
		24.000	941.873	1.951	159.685	512.354	188.397	81.437	*941.873*
		26.000	989.110	2.049	0.000	379.715	573.932	35.463	*989.110*
		28.000	2914.242	6.037	23.790	2323.340	476.790871	90.322	*2914.242*
		30.000	1397.226	2.895	24.671	603.222	749.334	20.000	*1397.226*
		32.000	2021.966	4.189	0.000	1419.936	595.030	7.000	*2021.966*
		34.000	2770.503	5.740	58.508	951.712	1758.694	1.589	*2770.503*
		36.000	14093.617	29.198	7669.791	5364.814	876.185	182.827	*14093.617*
		38.000	1092.176	2.263	0.000	247.670	526.348	318.158	*1092.176*
		40.000	4302.011	8.912	4110.236	164.242	17.966	9.567	*4302.011*
		42.000	7588.057	15.720	7342.491	47.061	198.505	0.000	*7588.057*
		44.000	1035.320	2.145	713.755	72.621	248.944	0.000	*1035.320*
		46.000	7381.699	15.293	3648.470	3577.891	120.563	34.774	*7381.699*
		48.000	562.830	1.166	534.806	0.000	0.000	28.024	*562.830*
		SubTotal	***48269.477***	***100.000***	***24339.716***	***16548.376***	***6484.804***	***896.581***	***48269.477***
		Totals	**92078.906**		**44197.763**	**30283.234**	**14958.022**	**2639.884**	**92078.903**

Table 8. Calculated length of the different thermal insulation condition sections for the mixture pipeline network system

					Insulation Condition (length, m)				
System	**Pipe Hierarchy**	**Nominal Diameter (in)**	**Total Length (m)**	**%**	**A**	**B**	**C**	**D**	**Subtotal**
Mixture	Mixture Pipe	10.000	1683.490	6.471	0.000	1197.912	338.872	146.707	*1683.490*
		16.000	23191.706	89.138	18526.178	992.411	3257.650	415.467	23191.706
		20.000	1142.591	4.392	86.545	139.485	874.188	42.373	*1142.591*
		Total	**26017.787**	**100.000**	**18612.723**	**2329.807**	**4470.710**	**604.546**	**26017.787**

According to the inventory results, about 80-82% of the lengths of each of the three pipeline networks that make up the fluid transportation system (HP, LP and M) have thermal insulations type A and B, while the remaining 18-20% have insulations with qualities C and D. The areas of the CPGF pipe network where insulations show greater deterioration degree, and therefore, are prone to induce a greater heat transfer to the environment, are those having a longer operation time. This is the case of CPU and CPD (Branch 1) pipelines.

The results of the inventory were eventually used as a key input data for the overall estimation of the heat losses related to the physical condition of the thermal insulation of the fluid transportation pipes, from the wells to the power plants.

The preliminary geographic database compiled during this work constitutes a foundation for the eventual integration of a complete inventory of the existing on-surface infrastructure in the CPGF, from which other practical applications related to operational activities, maintenance and design of the transport system could be tested.

On this last point, taking into account the experience gained in this work, it would be very advisable managing to have an up-to-date digital map of the CPGF steam field with photogrammetric precision so that all the spatial data relative to the surface infrastructure is properly referenced. We envision having a more reliable database that can be used for future surveys of different type, with support of modern technologies like GPS-based tracking devices and real-time mapping.

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