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PROGRESS IN THE DEVELOPMENT OF THE MODEL FOR FINDING HIGH pH SCC IN ARGENTINA

Daniel Falabella

Eduardo Carzoglio

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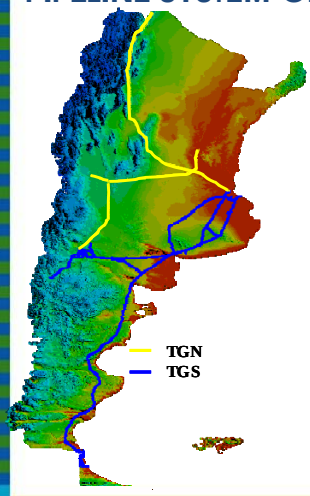
PIPELINE SYSTEM OF NATURAL GAS TRANSPORTATION IN ARGENTINA

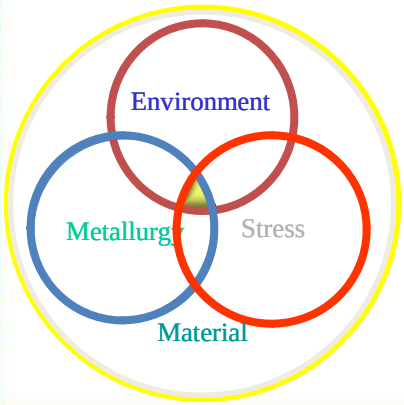


- 17000 km of high pressure Gas Pipelines
- 50 Compressor Plants
- Installed capacity: 946,400 HP
- Average age of the Transportation System: 35 years
- Diameters: 36” to 8”

Since 1992, the pipeline system has been operated by two companies:
TGS and TGN

WHAT IS SCC?

Stress Corrosion Cracking (SCC) appears as very thin, long and deep cracks, on the external surface of the underground pipelines.



Three conditions must be met concurrently for SCC; there must be a tensile stress, environment with specific characteristics, and a material susceptible to cracking in that environment.

If any one of these three conditions is not met, cracking either does not start, or it slows down, or stops.

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SCC IN ARGENTINA

In Argentina happened:

Four SCC failures while the system was in service

- 2 TGN (1996, 2002)
- 2 TGS (1998, 1999)

Eleven SCC failures on hydrotest

- 3 TGS
- 8 TGN

Twenty one Crack was detected by predictive model

- 17 TGS (over 100 SCC colonies)
- 4 TGN

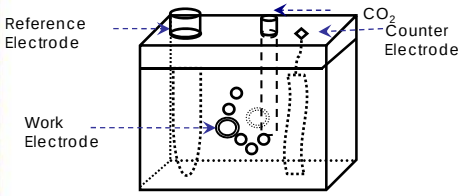
Corrosion Process Study

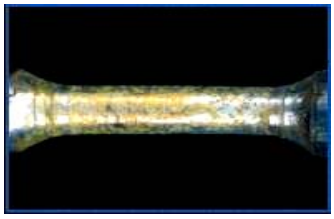
The objective is to reproduce the crack propagation model in laboratory.

Electrochemical test

Similar characteristic conditions of the soil found close the pipeline → Temperature Test → Cathodic Potential test:
1* -0.70 v Off
2* -1.2 v Off

Electrochemical Cell





Determination of microstructure → Determination of Hardness → Program of Mechanical Efforts

Corrosion Under Stress Test

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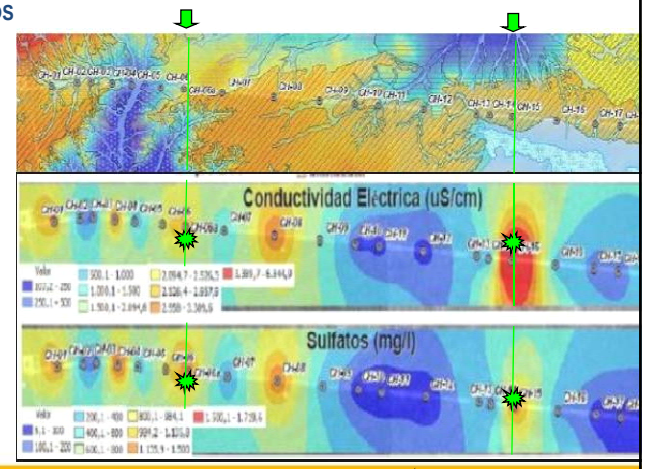
LABORATORY TEST RESULTS

With Cathodic protection Potential OFF –1.2 V	Without Cathodic protection Potential OFF –0.7 V
Sol. "Pipe/coating" pH sol decrease pH shielding coat increase NO CRACK	Sol. "Pipe/coating" Oxide Pits NO CRACK
CO_2 + Sol. "Pipe/coating" pH sol decrease TRANSGRANULAR CRACK	CO_2 + Sol. "Pipe/coating" pH sol decrease SMALL CRACKS
CO_2 + $CaCO_3$ + Sol. "Pipe/coating" pH range between 8-10 NO CRACKS	CO_2 + $CaCO_3$ + Sol. "Pipe/coating" pH range between 8-10 INTERGRANULAR CRACKS

SUSCEPTIBLE SOIL MODEL

- High resolution IKONOS images
- Conductivity
- Sulfate
- Sodium
- Potassium
- Carbonate + Bicarbonate
- Near Riverbeds
- Soil with deficient drainage
- Proximity to rectifier equipment



SCC sites

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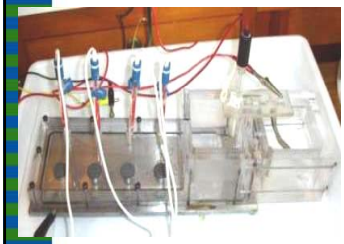
CATHODIC PROTECTION SHIELDS

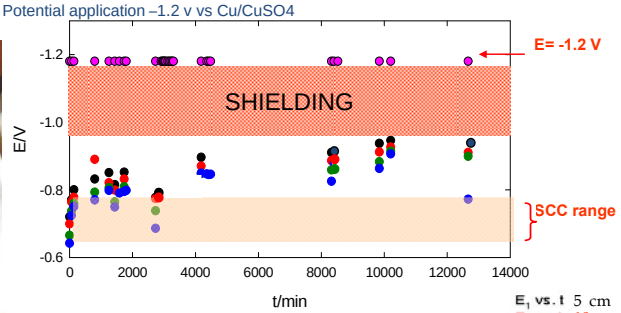
CP levels susceptible to SCC high pH takes place at a narrow potential interval where it coexists with Fe3O4 (-0.65mV and -0.75 mV)

In both companies all SCC cases happened near the rectifier equipment. less than 3 km

LABORATORY TEST

Potential application –1.2 v vs Cu/CuSO4

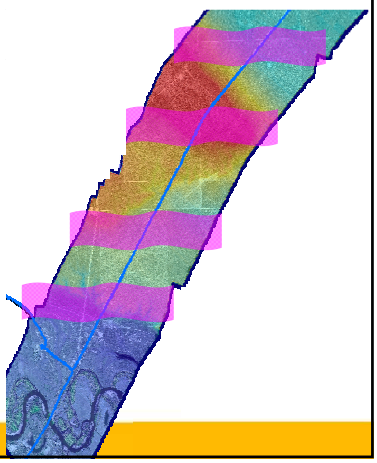




The effective potential recorded in the gap areas ranges from -0.7 V to -0.9 V.

DETERMINATION OF SCC SUSCEPTIBILITY AREAS

- Soil physical and chemical characteristics
- Pipe steel properties
- Operation pressure > 60% of SMYS
- Operation temperature >40 C
- Proximity to compressor station less than 30 km.
- Proximity to rectifier equipments less than 3 km
- Coating type: other than FBE
- Pipeline Coat > 10 years
- Evidence of coating damage by CIS and DCVG
- Density of shallow MFL failures <20%
- Residual stress (bend)
- History of the SCC leaks and ruptures



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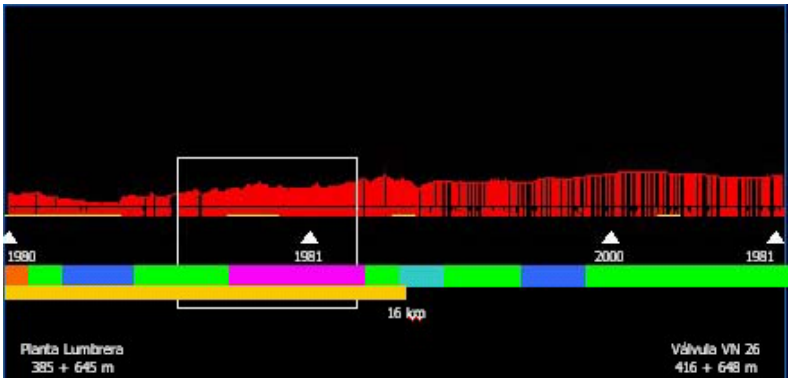
FIELD WORK

Based on the results of the research, soil studies, and considering all the variables, it is possible to outline and delimit the areas of highest susceptibility for carrying out direct field assessment

Through the application of this model in TGS 10 SCC sites were found and over 100 SCC colonies

TGN's ORIGINAL SOIL MODEL



TGN was developing a soil model to locate SCC when the 2002's rupture happened. The failure was about 12 km downstream a compressor plant, in an area with good drainage, foot hill pattern with a strong dry season.

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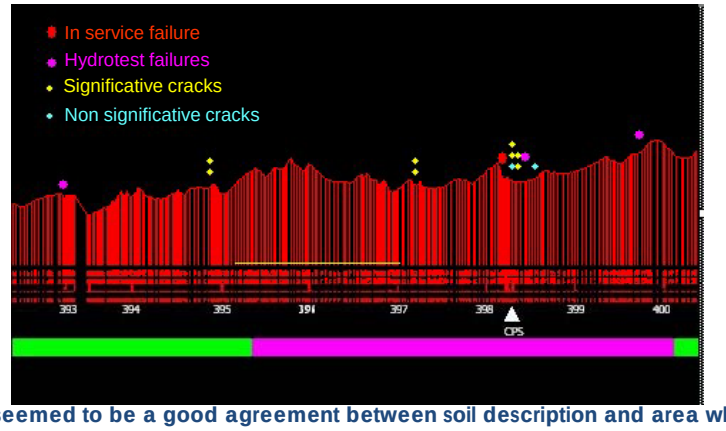
TGN's ORIGINAL SOIL MODEL



There seemed to be a good agreement between soil description and area where SCC failures in service, or in hydrotest (3) happened, or SCC colonies were found.

SOIL SAMPLES ANALYSIS

pH	Natural soil	Sample in contact with pipeline			
		No cracks	With cracks	Failure during hydrotest	Failure in service
pH < 8,5	11	11	2	0	0
8,5 < pH < 9	11	13	0	0	0
8,5 < pH < 9	8	1	0	0	0
9,5 < pH < 10	4	1	1	1	0
10 < pH	0	0	2	2	1
Average pH	9.57	8.51	9.36	10.43	10.40

During the tasks to restore the pipeline to safe service, we took soil samples from 35 sites. One sample from each natural soil stratus identified and another one taken against the pipe.

Results showed that pH was ever higher on the pipeline that in natural soil at same level and correlation between high pH on the pipe and SCC cracks

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SOIL SAMPLES ANALYSIS

CO_3H^-	Natural Soil	Sample in contact with pipeline			
Mili-equivalent / litter		No cracks	With cracks	Failure during hydrotest	Failure in service
$CO_3H^- < 2$	17	15	2	0	0
$2 < CO_3H^- < 4$	9	8	1	0	0
$4 < CO_3H^- < 7$	5	1	0	1	0
$7 < CO_3H^- < 10$	0	0	1	0	0
$10 < CO_3H^-$	0	2	1	2	1
Average concentration (meq/L)	2,32	3,32	18,68	248,83	78,70

Results also showed that CO_3H^- content was higher close to the pipeline that in natural soil at same level when SCC cracks were found

SOIL SAMPLES ANALYSIS

$Na^+ + K^+$	Natural Soil	Sample in contact with pipeline			
Mili-equivalent / litter		No cracks	With cracks	Failure during hydrotest	Failure in service
$Na^+ + K^+ < 10$	21	15	1	1	0
$10 < Na^+ + K^+ < 20$	7	4	0	0	0
$20 < Na^+ + K^+ < 30$	2	2	2	0	0
$30 < Na^+ + K^+ < 40$	0	1	0	0	0
$40 < Na^+ + K^+ < 50$	0	1	0	0	0
$50 < Na^+ + K^+ < 100$	1	1	1	1	0
$100 < Na^+ + K^+$	0	2	1	1	1
Average Concentration (meq/L)	9.10	27.20	51.49	256.97	152.60

Results showed that $Na^+ + K^+$ content was higher close to the pipeline that in natural soil at same level when SCC cracks were found

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TGN MODIFIED SOIL MODEL

1. **Identified areas to probable susceptibility to SCC**
   - Pipeline older than 10 years
   - Operation stress > 60% SMYS
   - Operation temperature > 37°C
   - Distance to discharge of Compressor Plant < 32km
   - Asphalt enamel or plastic tape coating
2. **Field site selection based on topography and drainage**
3. **Soil sampling and analyzing**
4. **Definition as susceptible areas where**

   pH > 9

   CO_3H^- > 4 meq/L

   $Na^+ + K^+$ > 10 meq/L

TGN MODIFIED SOIL MODEL

From 2002 to 2005

- 17 segments at plant discharges identified as SCC susceptible
- 562 sites selected for soil sampling
- 1828 soil samples analyzed
- 48 soil samples applied as susceptible to SCC
- 5 hydrotest done at plant discharges

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HYDROTEST RESULT

Plant 1

- 42 years old line
  - Highest susceptibility to SCC
  - 4 SCC failures during hydrotest
- 28 years old line
  - Low susceptibility to SCC ;different coating condition
  - No failures during hydrotest

Plant 2

- 42 years old line
  - High susceptibility, 1 previous failure in service
  - 1 failure during hydrotest

HYDROTEST RESULT

Plant 3

- 42 years old line
  - Low susceptibility to SCC
  - No failure during hydrotest

Plant 4

- 42 years old line
  - No susceptibility, same soil description in 2002 failure
  - No failure during hydrotest

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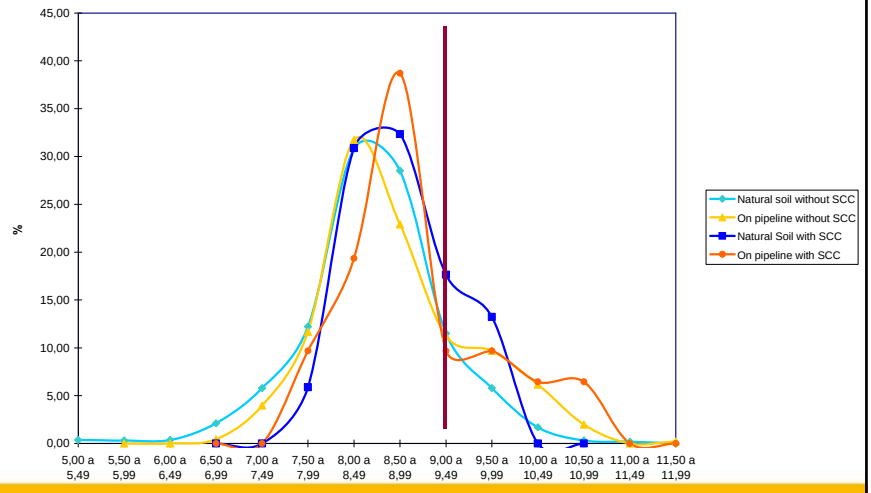
RESULT OF SOIL ANALYSIS



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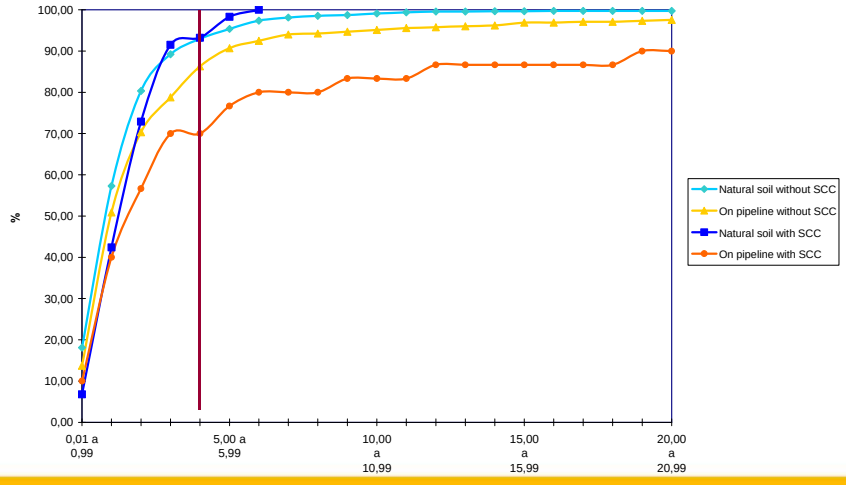

CO_3H^- - meq/L

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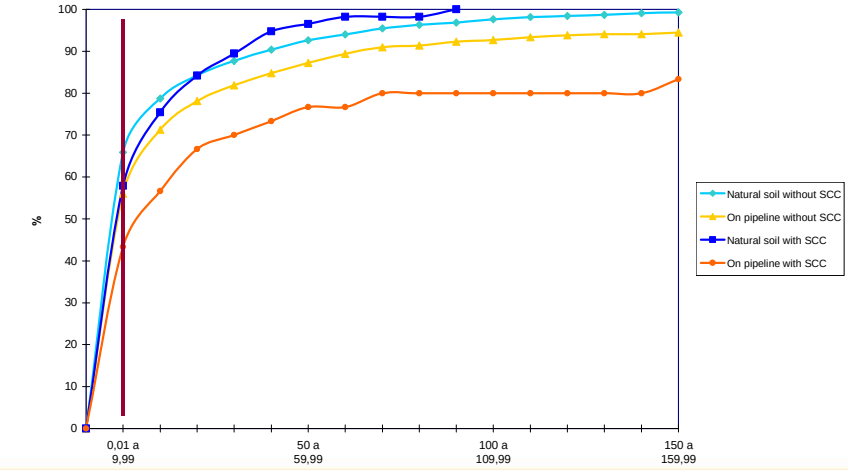
RESULT OF SOIL ANALYSIS



$Na^+ + K^+$ - meq/L

CONCLUSIONS

- Through systematic soil sampling and its analysis soil features compatible with SCC presence have been identified.
- This allowed to allocate resources more efficiently since the focus was changed from making a few large excavations to perform numerous small excavations to take soil samples.
- From the results of soil analysis made from the characteristics defined, it is possible to define a relative susceptibility to the existence of significant SCC cracks colonies.
- This process does not invalidate topographic identification and the drainage of soil susceptible to SCC, rather it supplements them.
- Soil samples must be taken from sites on which both situations have been previously identified.
- The results obtained also stress the active role played by the poor condition of the existing asphalt coating and the cathodic protection system installed to protect the pipeline against corrosion.

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CONCLUSION

- It is evident that the high current drainage (higher than 50A per unit) of the impressed current cathodic protection units, when it creates a strong alkalization of the pipeline surface, simultaneously creates the adequate environment to develop SCC.
- All SCC cases recorded occurred at a distance from cathodic protection units closer than 3 km, for that reason there have been surveys on the likelihood of cathodic protection shielding in these areas
- The other two necessary conditions, susceptible material and high cyclical pressures already exist due to the type of pipeline steel and the normal operating conditions.
- The environmental and operational factors that determine the micro-environment in the areas where high pH SCC has been found.
- High pH SCC cracks have been re-created in laboratory in an electrolyte with the same features as the solution found at a site where SCC occurred along pipeline system.

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