Economical and technical evaluation of PE100 pipes used in natural gas distribution systems

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Transmission & Distribution
Evaluation of Polyethylene and Polyamide gas pipes

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Petrobras Distribuidora (BR) and Mitsui Gas run natural gas distribution companies in Brazil.
(BR is an operating company, and Mitsui Gas is a holding company of 7 LDCs)

<table>
<thead>
<tr>
<th></th>
<th>Number of Customers</th>
<th>Pipe network length (km)</th>
<th>Volume (x10³ m³/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BR</td>
<td>29,083</td>
<td>432</td>
<td>3,950</td>
</tr>
<tr>
<td>Mitsui*</td>
<td>128,804</td>
<td>3,927</td>
<td>13,010</td>
</tr>
</tbody>
</table>

As of July 2014, *Total of 7 LDCs
Natural gas distribution in Brazil
• A concession area is on an entire state bases (except for SP and Rio de Janeiro states)
• In most states, supply of natural gas has 20 years experiences.
• Development of residential market in recent years leads to a formation of PE pipe networks in urban areas.

Our philosophy in network formation
• `Efficient and economical gas pipe network` 
• It is one of key factors to choose most suitable pipe material.
  => Comparison of PE100 pipe and PE80 pipe

Terminology
• `PE100 pipe` = PE pipe composed of PE100 resins
• `PE80 pipe` = PE pipe composed of PE80 resins
2. A business dilemma

Squeeze-off

- Makes use of flexibility of PE pipe
- An effective flow-stopping measure in an emergency or even in ordinary operation
- Pipes are squeezed together thus preventing the flow of gas and isolating the pipe section.
- Uses specially designed tools
- Usually re-rounding is done after squeeze-off.

Advantage, Disadvantage of PE100 pipe and Squeeze-off

<table>
<thead>
<tr>
<th>Advantage in comparison with PE 80</th>
<th>Disadvantage in comparison with PE 80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Realizes a higher tensile strength with greater resistance against slow and fast crack propagation</td>
<td>PE100 material is <code>harder</code> =&gt; Concerns about damages and pipe wall thinning by squeeze-off</td>
</tr>
<tr>
<td>Enables higher operational pressures, larger flow capacity in an economical manner</td>
<td></td>
</tr>
</tbody>
</table>

Damage
Pipe wall thinning
### Application of Squeeze-off to PE 100 Pipes

Examples of concerns and restrictions about application of squeeze-off to PE100 pipes:

<table>
<thead>
<tr>
<th>Concerns and Restrictions</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Equipment for squeeze-off of PE pipes is available on the market, but the effect of the squeezing on the long-term strength of PE 100 water pipes is still not fully studied&quot;</td>
<td>The Nordic Plastic Pipe Association (Sweden), PE Pressure pipe system, 2012</td>
</tr>
<tr>
<td>&quot;Reference should be made to the relevant pipe manufacture for specific advice regarding squeeze-off operations on PE 100 pipes (stress cracking could occur and mechanically-aided re-rounding would be required)&quot;</td>
<td>Institute of Gas Engineers and Managers (UK), IGEM/TD/3 Edition 5, 2014</td>
</tr>
<tr>
<td>&quot;After the squeeze-off procedure is complete the pipe must be: - Inspected and re-rounded if necessary; - Renewed if there are any signs that the pipe is damaged, i.e., splitting or cracking.&quot;</td>
<td>GPS PE Pipe Systems (USA), Installation and Technical Guidelines, 2011</td>
</tr>
<tr>
<td>“After squeeze-off of the pipe (PE100), the section should be reinforced with mechanical clamp” (Translation by the author)</td>
<td>Japan Polyethylene Pipes Association for Water Service (Website)</td>
</tr>
</tbody>
</table>
3. Technical issues related to squeeze-off of PE-100 pipes

How to cope with the problem when we need to stop gas flow?

- Can we close valves?
  - Yes (Not easy in urban area)
  - No (=need to use squeeze-off)

- Do we replace or reinforce after squeeze-off?
  - No
    - Velocity control of squeezing & release <Difficult>
    - Inspection of INTERNAL damage from OUTSIDE <Not yet established>
  - Yes

**Replacement vs Reinforcement**

<table>
<thead>
<tr>
<th>Replacement</th>
<th>Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need to</td>
<td>Can be the most practical and the easiest solution when it is not possible to close valves</td>
</tr>
<tr>
<td>• wait and close valves, or</td>
<td></td>
</tr>
<tr>
<td>• do another squeeze-off</td>
<td></td>
</tr>
<tr>
<td>&lt;Difficult, not realistic&gt;</td>
<td></td>
</tr>
</tbody>
</table>

End
4. Procedure of squeeze-off and reinforcement

Target of the studies
To establish a method and procedure of reinforcement which ensures long-term integrity of squeezed-off PE 100 pipes

Main points of studies
1. Taking `Viscoelasticity` and `Elastic rebounding` of PE material into consideration, we prepared 10 test pipes (PE100, Ø 63mm, SDR11) to evaluate
   1) squeeze-off time effect,
   2) re-rounding time effect,
   3) re-rounding tool geometry* effect, and
   4) effectiveness of coupler and saddle reinforcement fittings.
   10 pipes are different one another in duration of squeeze-off (Tsq), duration of re-rounding (Trr), re-rounding tool geometry, and fitting type (coupler/saddle).
   *: Circular and Elliptical (Flattening=9.5%)
2. Comparison of PE100 pipe and PE80 pipe based on actual projects in terms of
   1) Network flow capacity, and
   2) Installation costs
4. Procedure of squeeze-off and reinforcement

Tests and Measurement of deformation

- Direction of squeezed-off: vertical;
- Measurements: vertical diameter (Dv) and horizontal diameter (Dh) at two points (See the left figure);
- Two measure points: distance of them = a length of reinforcement coupler, i.e., where electro-fusions are realized;
- Reason of the selection of the points: roundness after re-rounding is important to assure sound electro-fusion and mechanical integrity of reinforcement;
- Timing of measurement:
  1) before squeeze-off, 2) after squeeze-off and 3) after re-rounding

**Deformation ratio**
Ex. `A deformation ratio of 0.9` means that a pipe diameter has changed to 90% of its original diameter.
4. Procedure of squeeze-off and reinforcement

Squeeze-off time effect

- Relationship between squeeze-off duration and the resulting deformation
- Results - Deformation by squeeze-off increases proportionally to the logarithm of Tsq (Duration of squeeze-off).
- The ambient temperature was 26-28°C.
- The results conform to viscoelasticity of polymer material.
4. Procedure of squeeze-off and reinforcement

Re-rounding time effect

- The objective - to find out the optimum duration of re-rounding (Trr) in order to establish effective operations (Should we keep re-rounding for 1 hour or 1 minute?)
- Re-rounding effect (A/B): How much does the re-rounding operation make the pipe recover its original shape?

\[
\text{Re-rounding effect} = \frac{\text{Deformation ratio after squeeze-off}}{\text{Deformation ratio after re-rounding}}
\]

The table below shows an example of the calculation of the re-rounding effect:

<table>
<thead>
<tr>
<th>Dv</th>
<th>Circular</th>
<th>Trr 20 min.</th>
<th>Trr 10 min.</th>
<th>(a/b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>After squeeze-off (A)</td>
<td>0.915</td>
<td>0.915</td>
<td></td>
<td></td>
</tr>
<tr>
<td>After re-rounding (B)</td>
<td>0.984</td>
<td>0.981</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Re-rounding effect (A/B)</td>
<td>0.930 (a)</td>
<td>0.933 (b)</td>
<td>0.997</td>
<td></td>
</tr>
</tbody>
</table>

- The ratio of Re-rounding effects (a/b) shows "How are the re-rounding effect of duration 20 min and that of 10 min close?" In the above case, a/b = 0.997. Note that A/B and a/b are different. Now let’s concentrate on a/b.
4. Procedure of squeeze-off and reinforcement

**Re-rounding time effect** (continuation)

- The table below summarizes all the values of a/b in four cases (Circular/Elliptical, Dh/Dv) (Duration of squeeze-off (Tsq) were 40 min in all cases).

<table>
<thead>
<tr>
<th>Re-rounding tool</th>
<th>Dh or Dv</th>
<th>a/b value (Ratio of re-rounding effects between 20 min and 10 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular</td>
<td>Dh</td>
<td>1.010</td>
</tr>
<tr>
<td></td>
<td>Dv</td>
<td>0.997</td>
</tr>
<tr>
<td>Elliptical</td>
<td>Dh</td>
<td>0.990</td>
</tr>
<tr>
<td></td>
<td>Dv</td>
<td>1.011</td>
</tr>
</tbody>
</table>

- Since the a/b values are very close to one (1) (actually they are all within 1±1.01%), there is little difference of the effect of the duration of re-rounding between 10 min. and 20 min. at temperature 26-28°C.
- Therefore, most of the re-rounding deformation must have completed within 10 min. => Keeping re-rounding for 10 min can be sufficient to recover the roundness at above said temperature.
- The finding can help realize secured and effective re-rounding/reinforce work at site.
4. Procedure of squeeze-off and reinforcement

Re-rounding tool geometry effect

- Considering the work procedure of reinforcement (to be described later), it is important to obtain high degree of roundness by re-rounding.
- Why?
  1) a reinforce coupler needs to pass the squeezed-off/re-rounded section;
  2) high degree of fusion of resin needs to be realized between the coupler and a pipe body to ensure mechanical integrity of the reinforcement.

- Therefore, we conducted tests to see the effects of re-rounding tool geometry on the recovery of roundness.
- Two types of tools: (a) circular and (b) elliptical, as shown in the left side figure
- Note that the ratio between long axis and short axis of elliptical type is around 0.90 (=59.85/66.15) (Flattening=9.5%).
4. Procedure of squeeze-off and reinforcement

Re-rounding tool geometry effect (continuation)

- The results are summarized in terms of Oval ratio \(=D_{\text{min}}/D_{\text{max}}\) in the table below. (\(T_{\text{rr}} = 20\) min in all cases)

Note that the closer to one (1) is an Oval ratio, the closer to circular is the shape.

<table>
<thead>
<tr>
<th>Re-rounding tool</th>
<th>Squeeze-off duration</th>
<th>Oval ratio after re-rounding</th>
<th>Minimum Oval ratio *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular</td>
<td>40 min.</td>
<td>0.973</td>
<td></td>
</tr>
<tr>
<td>Elliptical</td>
<td></td>
<td>0.991</td>
<td></td>
</tr>
<tr>
<td>Circular</td>
<td>120 min.</td>
<td>0.969</td>
<td>0.969 ((\varnothing) 63) OK!</td>
</tr>
<tr>
<td>Elliptical</td>
<td></td>
<td>0.998</td>
<td></td>
</tr>
</tbody>
</table>

* Brazilian standard NBR 14462

- Result - **elliptical type is better than circular type**: the oval ratios of elliptical type are within 1% from 1.0, whereas the ratios are within 2-3% from 1.0 with circular type.

  The results can be related to `elastic re-bounding` of PE pipe when unloaded. To compensate the re-bounding, it is necessary to `over-compress` to the horizontal direction in re-rounding. The elliptical type can realized it, but the circular type cannot. All the results satisfy the Brazilian standard as shown in the table (\(\varnothing\) 63).

- It is recommended to use an elliptical type for re-rounding.
4. Procedure of squeeze-off and reinforcement

Effectiveness of coupler and saddle reinforcement fittings

Reinforced pipe submitted to hydrostatic test (Cross section)

A hole was made artificially to simulate the situation that Slow Crack Growth, initiated at damages by squeeze-off at inner surface, reaches the outer surface.
4. Procedure of squeeze-off and reinforcement

Reinforcement fittings – Hydrostatic tests

- Short and long term accelerated hydrostatic tests (ISO 1167)
- 8 test pipes after squeeze-off, re-rounding, perforation and reinforcement
- All tests cleared short term and long term tests without any leakage

<table>
<thead>
<tr>
<th>Test type</th>
<th>Circumferential stress $\sigma_c$</th>
<th>Required Min. Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short term resistance to pressure at 80$^\circ$C</td>
<td>5.5 MPa</td>
<td>165 hours</td>
</tr>
<tr>
<td>Long term resistance to pressure at 80$^\circ$C</td>
<td>5.0 MPa</td>
<td>1,000 hours</td>
</tr>
</tbody>
</table>
4. Procedure of squeeze-off and reinforcement

Reinforcement fittings – Rupture tests

• 4 samples after the short and long term tests to compare the strength of reinforcement (coupler and saddle) in comparison to the pipe body
• In all cases, ductile rupture occurred in pipe body
• Results show that the reinforced part has more strength than pipe body after 1,000 hours hydrostatic pressure under accelerated condition.
4. Procedure of squeeze-off and reinforcement

**Reinforcement method with coupler**

- Tests showed that reinforcement fitting has more resistance than the pipe’s body itself, and so it can assure long term integrity.

- A reinforcement method with coupler was proposed by SEKISUI, a Japanese polyethylene supplier, and is used in Japanese water industry.
4. Procedure of squeeze-off and reinforcement

Suggested squeeze-off and reinforcement procedure

• Always do reinforcement when squeeze-off is applied to PE 100 pipes (unless effective inspection and evaluation method of internal damage is established);

• Always do re-rounding with at least 10 minutes;

• An elliptical type is preferable for re-rounding;

• Try to use a coupler EF joint reinforcement which is full encirclement type. A saddle type is acceptable if there is difficulty to slide the coupler joint;

• Register the squeezed-off point in GIS and monitor in an Integrity Management Plan.
5. Comparisons between PE100 and PE 80

City of Vitória – Espírito Santo
5. Comparisons between PE100 and PE 80

Simulated grid – PE100 (⌀63)

Flow Capacity
Maximum Operational Pressure 0.7 MPa
Maximum flow capacity: **17,722 m³/hour**
5. Comparisons between PE100 and PE 80

Simulated grid – PE80 (Ø63)

Flow Capacity
Maximum Operational Pressure 0.4 MPa
Maximum flow capacity: 10,518 m³/hour
5. Comparisons between PE100 and PE 80

Installation Costs

In order to compare installation costs:

- Service costs were referenced to bid prices put forward by a contractor in 2013 to construct a network in the neighboring cities of Vila Velha and Serra.

- Material prices were checked with a national supplier. PE100 pipes were 12% more expensive than PE80 pipes.

**PE100 (Ø63)**

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service cost</td>
<td>US$ 3,685,665.65</td>
</tr>
<tr>
<td>Material cost</td>
<td>US$ 188,749.13</td>
</tr>
<tr>
<td>Total cost</td>
<td>US$ 3,874,414.78</td>
</tr>
</tbody>
</table>

**PE80 (Ø63)**

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service cost</td>
<td>US$ 3,685,665.65</td>
</tr>
<tr>
<td>Material cost</td>
<td>US$ 168,526.09</td>
</tr>
<tr>
<td>Total cost</td>
<td>US$ 3,854,191.74</td>
</tr>
</tbody>
</table>
5. Comparisons between PE100 and PE 80

Flow capacity comparison
PE100/PE80 = 17,722/10,518 = 1.68
PE100 pipe has 1.68 times more flow capacity than PE80 pipe.

Installation cost comparison
PE100/PE80 = 3,874,414.78/3,854,191.74 = 1.0052

Summary of comparison
Flow capacity increase  PE100 (⌀63)/PE80 (⌀63): +68%
Installation cost increase PE100 (⌀63)/PE80 (⌀63): +0.52%
6. Conclusions

- It is recommended to do reinforce to all PE 100 pipe section where squeeze-off is applied;

- The shape of roundness, which is obtained through re-rounding operation, is vital for secured reinforcement. Elliptical type re-rounding device has better re-rounding capacity than circular type and is recommendable;

- All reinforced PE100 pipes using EF coupler and EF saddle have passed accelerated 1,000 hours hydrostatic tests without any leakage;

- Reinforced part has more mechanical strength than the pipe body against internal pressure. Therefore, reinforcement can assure long term integrity of squeezed-off PE100 pipes;

- When comparing a PE100 with a PE80 pipe network, the first one may have a 1.68 times higher flow capacity with less than 1% increase in total installation costs.
Thank you!

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