Rapport SGC 096

LIFETIME OF PE-PIPES SUBJECTED TO SQUEEZE-OFF

Final report

Tomas Tränkner

Studsvik Polymer

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STUDSVIK/M-97/92

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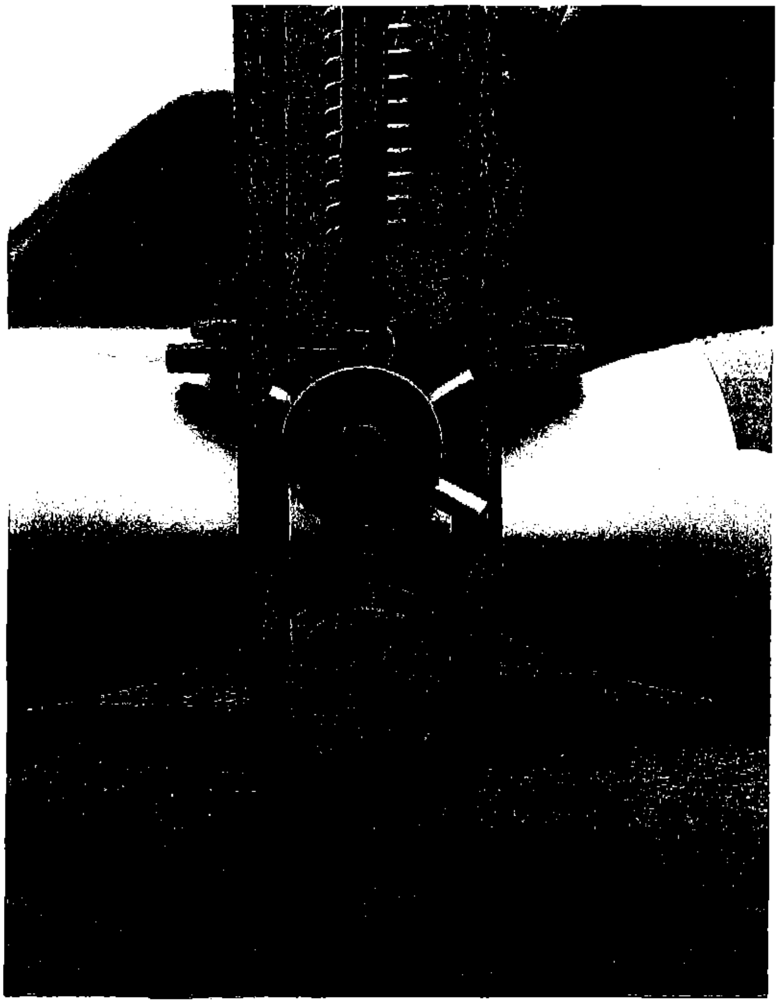

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The Swedish Gas Technology Center
SGC proj. 94-22

LIFETIME OF PLASTIC PIPES SUBJECTED TO SQUEEZE-OFF

SGC proj. 94-22

Final report

Summary

This final report covers an investigation of lifetime of plastic pipes subjected to squeeze-off. Squeeze-off is a commonly used practice for the control and shut off of gas flow in PE-pipes. Two circular bars are squeezing the pipe walls together. The first part of the report presents a literature summary within squeeze-off and also the results from direct contact with industries regarding squeeze-off procedures and current code-of-practice in different countries. The most important squeeze-off parameter is the wall compression (how much the pipe is compressed). As long as the amount of wall compression is lower than 30 % it is considered as safe to use squeeze-off for shut off gas.
The second part of the report presents the results from hydrostatic pressure testing of MDPE-pipes subjected to squeeze-off. Pressure testing has been performed on 28 pipes, Ø=63 mm and Ø=160 mm, in air at 80°C and in detergent at 95°C. The longest testing time is 20 688 h. The results may indicate some loss in lifetime, however not substantial, of the pipes due to the squeeze-off procedure. But the lifetime of the pipes subjected to squeeze-off is probably at least 50 years at 20°C and 4 bars.

Reviewed by

Stefan Erkselius

Approved by

Ulrika Andersson

P/TT

Sammanfattning

Denna slutrapport redovisar en undersökning angående livslängd hos sammanklämda PE-rör. Sammanklämning är en vanlig metod för att kontrollera eller stänga av gasflödet i PE-rör. Två runda stänger pressar ihop PE-röret så att dess innerväggar möts. Första delen av rapporten presenterar resultaten från en litteraturstudie inom sammanklämning och även resultaten från direktkontakt med gasdistributörer angående förekommande sammanklämningsrutiner och rekommendationer. Den andra delen av rapporten presenterar resultaten från praktiska livslängdsundersökningar av PE-rör som sammanklämts på olika sätt. Resultaten av litteraturundersökningen, som utfördes 1995, är i sammanfattning följande:

* Det finns inga rapporterade fälthaverier i Europa hos PE-rör som varit orsakade av sammanklämning.
* Sammanklämningsgraden är den enskilt viktigaste faktorn. Rörväggarna bör ej tryckas ihop mer än 30 % av dubbla godstjockleken.
* Så länge som sammanklämningen ej är för stor (>30%) orsakar återrundning ingen skada på rören.
* Det måste finnas stoppklackar på sammanklämningsverktyget så att röret ej kan klämmas för mycket.
* Det är viktigare att lossa sammanklämningsverktyget långsamt än att trycka ihop långsamt.
* Det sker ingen stor utveckling av sammanklämningsverktyg. Gasbolag modifierar och förbättrar själva sammanklämningsverktygen.
* British Gas tillåter inte (1995) sammanklämning av deras nyligen installerade PE 100 material.

Den praktiska undersökningen omfattade provning av Dy= 63 mm och Dy=160 mm PE-rör. Sammanklämning utfördes med två metoder enligt Sydgas rutiner. Följande resultat erhölls från livslängdsundersökningarna av sammanklämda rör:

* Dy=63 mm PE-rör har troligen en längre tid till Stadie II (tid till sprödbrott) än Dy=160 mm rör. OBS, detta gäller endast för de undersökta PE-rören, andra PE-rör kan uppföra sig annorlunda beroende på råvara, extruderingsbetingelser etc..
* För vissa av de stora rören som sammanklämts (Dy=160 mm) har kortare brottider erhållits. Detta kan vara en indikation på att sammaklämningen medfört en kortare tid till Stadie II.
* Några av de stora DY=160 mm PE-rören har många sekundära sprickor på insidan. Det stora antalet och storleken på sprickorna är ovanligt.
* "Katastrofsammanklämning" tycks inte vara kritiskt för PE-rörens livslängd.
* För Dy=63 mm PE-rören tycks sammanklämning inte ha någon kritisk inverkan på livslängden.
* Livslängden hos de undersökta PE-rören som sammanklämts är troligen minst 50 år vid 20°C och 4 bar.

P/TT

List of content

1 Introduction

Squeeze-off is a procedure to shut off and control gas flow in plastic pipes when it is necessary to perform reparation or maintenance of the piping system. In this procedure, the pipe is compressed between two parallel bars until the inside walls meet so the gas flow is shut off. The squeeze-off of plastic pipes is attractive in several ways: It is a very simple, fast and cheap way to shut off the gas. The disadvantage with squeeze-off is the potential risk of damage the pipe material and cause crack initiation spots. Field failures in pipe distribution systems in the USA have shown several examples of failures caused by squeeze-off. Therefore it is of great concern to define what conditions squeeze-off may be harmful for the lifetime of the pipe distribution system.

As the squeeze-off procedure is individual for almost all gas utilities it was important to evaluate the current squeeze-off method used in Sweden, but also to investigate what procedures were used by other utilities and collect facts regarding recommendations and current research. The principles for squeeze-off is shown in Figure 1.

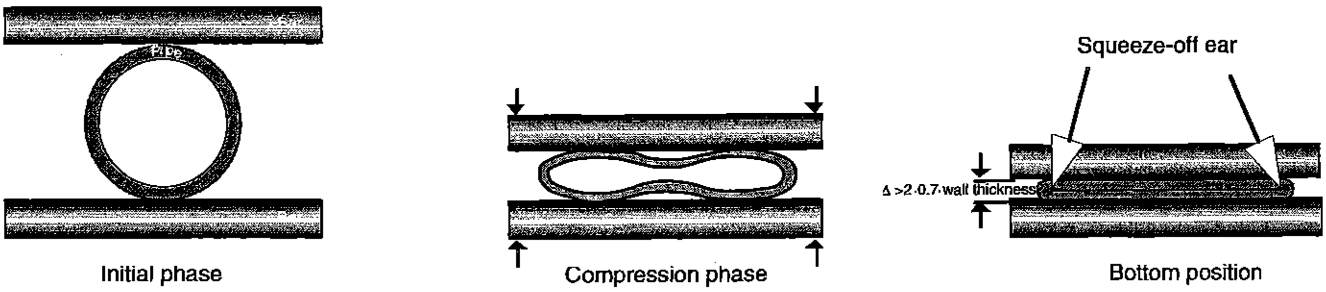


Figure 1
Squeeze-off of a PE-pipe. Two bars compress the pipe until the inner surfaces meet and close. In order to stop a gas flow the distance between the bars must be 10-20 % less than twice the wall thickness of the pipe. The bars are moved by a screw driven tool or by a hydraulic jack.

2 Method of approach

2.1 Objectives

The objectives of the work are the following:

* Judge whether PE-pipes subjected to squeeze-off will withstand a 50 years lifetime in service.

* Check how the lifetime of PE-pipes is affected by "catastrophic" squeeze-off compared to "normal" squeeze-off.

* Generate long term hydrostatic pressure testing data in order to show whether squeezed-off PE-pipes will last for 50 years in service.

* Check the lifetime of squeezed-off PE-pipes compared to normal unsqueezed pipes.

* Investigate the influence of low temperatures (range +10 to -20°C) on squeeze-off.

2.2 Working specification

The project is divided into a literature survey and an experimental program. The project is performed in three steps of one year each. The literature survey deals with lifetime of PE and Nylon pipes subjected to squeeze-off. The experimental program is divided into specimen preparation (performing the squeeze-off operation and documentation), hydrostatic pressure testing at 80 and 95°C and finally post analysis of exposed pipes. The project is financed by the Swedish Gas Technology Center.

3 Investigated materials

Two pipe grades are included in the project, Ø=160 and 63 mm, SDR 11. The pipes were extruded by Nordisk Wavin A/S in Denmark with Finathene 3802 YCf resin. Finathene is a common resin for polyethylene gas pipes in Sweden. The pipes grades included in the experimental program is presented in Appendix A.

4 Literature survey

4.1 Approach

The aim of the literature survey was to summarize the available information regarding squeeze-off of polyethylene and polyamide (PA 11=Nylon 11) pipes. Information was collected in data bases and by direct contacts with resin producers, pipe manufacturers, tool manufacturers and end users. The following specific questions were addressed in the survey:

* What reports and articles are published within squeeze-off of PE and PA11 pipes, and what is mentioned in these reports regarding lifetime of pipes subjected to squeeze-off?

* What types of squeeze-off procedure is used in different countries such as France, Italy, Great Britain, Denmark and Sweden?

* What kind of information is available from resin manufacturers and pipe producers regarding squeeze-off. Do the resin manufacturers and the pipe producers consider squeeze-off as a problem, and if so during what conditions?

4.2 Data base search

The data base search was performed by the Royal Institute of Technology at Studsvik in RAPRA, Engineering Materials Abstract and NTIS. The following key-words were used: squeeze-off, pipe, gas, distribution, polyethylene, PE, polyamide 11, PA 11. Data were also collected from the data base at Studsvik from symposium proceedings (Plastics Pipe Conference, Int Plastic Fuel Gas Pipe Conf, Int Gas Research Conference). A summary of different standards are also presented.

The data base search gave only a few references. It is basically three places where extensive tests have been performed on squeezed pipes: At Battelle in the USA, at Tokyo Gas/Showa Denko and in Canada by Charrier et al. Below a summary of their reported results is presented.

4.2.1 Work done at Battelle in the USA

The extensive work done by Battelle is published in several reports (1-7). Below some of the most important conclusions and recommendations from their work are listed.

The following parameters (Ref 3) will influence the damage in pipes subjected to squeeze-off: Material, pipe diameter, wall thickness, SDR, tool design, squeeze-off temperature, compression rate, wall compression, time compressed, release rate, rerounding and post-squeeze-off reinforcement.

Below some important findings are presented for the above parameters:

Material
The risk for a failure of the pipe due to squeeze-off is dependent on the slow crack growth resistance of the material.

Pipe diameter, wall thickness and SDR (Dy/wall thickness)
If the wall thickness increase the bar diameter must increase proportionately.

Tool design
Single small diameters bars tends to increase the likelihood of damage. For pipe diameter greater than 50 mm the diameter of the bars should be at least four times the wall thickness, then if the wall compression is maximum 30 %, damage of the pipe material is unlikely to occur. For larger pipe diameters the tool diameter should also be larger.

Squeeze-off temperature
The effect of temperature is material dependent. If the stiffness of the material is very temperature dependent the squeeze-off damage is more likely to occur. British Gas have met problems in squeeze-off with PE 100 materials at 0°C, see 4.3.1.

Compression rate
Pipes should be compressed as slowly as possible. Test results suggest a compression rate of 50 mm/min or less.

Wall compression
Definition of wall compression: 0 % wall compression implies the pipe walls are not compressed but just are touching. 100 % wall compression implies the bars have completely compressed the pipe wall and are touching. The greater the pipe wall is squeezed the greater is the amount of wall compression.

The practical limits of the squeeze-off should lie between flow stoppage and the onset of damage. The gas industry in USA typically compresses the wall thickness no more than 30 % at squeeze-off.

In Europe the term "squeeze-off level" is sometimes used instead of "wall compression". The squeeze-off level is equal to 100 -the wall compression (70 % squeeze-off level is equal to 30 % wall compression).

Time compressed
The length of time the pipes is compressed is of less importance in the likelihood of inducing damage.

Release rate
Release rate is believed to be more important than the compression rate. The pipe should be released as slowly as possible. A release rate of less than 12.5 mm/min do not increase the likelihood of damage. Release rate of screw driven tools are not likely to cause any problems. Some hydraulic operated tools may open quite rapidly and therefore measures should be taken to limit the rate of opening of hydraulic tools.

Rerounding
Rerounding can result in beneficial compressive stresses on the inside of the squeeze ear in materials undamaged during the squeeze-off procedure. However, if the squeeze ear is damage then rerounding may enlarge the damage even more.

Post-squeeze-off reinforcement
Sometimes gas utilities install reinforcement sleeves around the pipe after squeeze-off. The reinforcement causes compression forces around the pipe wall at the squeeze and this is assumed to prevent crack growth. Field experience showed that a squeeze-off defect will grow underneath a

reinforcement clamp. This suggest that a reinforcement clamp may not be able to generate enough compressive stress to limit defect growth.

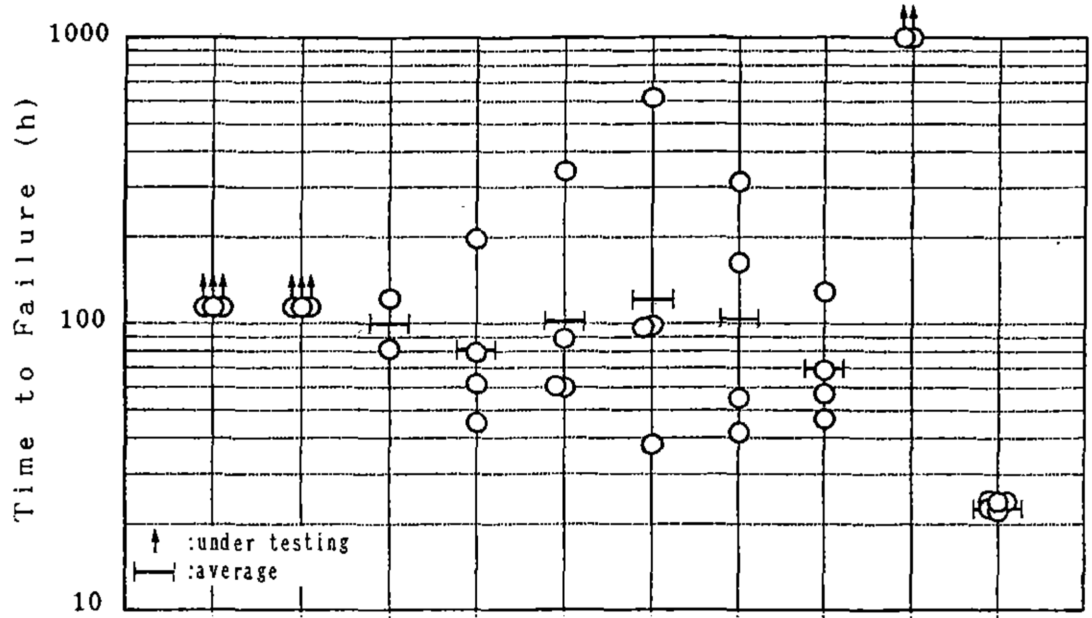
The most important factors for the squeeze-off operation are: Pipe wall, wall compression, pipe wall thickness and tool geometry [6]. Ref 7 finds that the percentage squeeze is the parameter that most affects the performance of the pipe.

In Ref. 1 the effect of squeeze-off on pipe dimension (Ø=50-150 mm) and tool bar geometry (Ø=25-100 mm) was investigated. They made the following conclusions:

* The pipes were damaged if wall compression was greater than 30 % and they recommended only a 20 % or less wall compression.
* The squeeze bar size should be large compared with pipe diameter.
* Flat bars are more effective in shutting off gas but may cause more damage.
* It is crucial that the squeeze off tool have stops that are set to the proper specifications. Too much wall compression is the greatest contributor to potential pipe damage.

4.2.2 Work done at Tokyo Gas and Showa Denko

In Ref 8 the effect of three squeeze-off parameters was investigated: squeeze-off temperature (-5, 23 and 40°C), compression rate (5 and 20 mm/min) and release speed (10 and 100 mm/min). The wall compression was 30 %. They performed the squeeze-off tests on 165x13.5 mm pipes. The results showed that the squeeze-off damage was independent of compression rate but dependent on squeeze-off temperature: The higher the temperature the more sever damage of the squeezed-off pipe. The reason is due to the easier flow of the resin at a higher temperature and more wrinkles may be formed (8). The failure time in a four point bend test, at constant load at 80°C in detergent, was recorded for the different squeeze-off combinations. The results are shown in Figure 2.



Experiments NO.	1	2	3	4	5	6	7	8	Not Squeezed	Notched
Temperature (K)	268	268	296	296	313	313	296	296	–	–
Squeezing sp. (mm/min)	5	20	5	20	5	20	5	20	–	–
Releasing sp. (mm/min)	10	100	100	10	100	10	10	100	–	–

Figure 2
Results from four point bend testing at 80°C in detergent.(Ref. 8).

Figure 2 shows clearly how squeezed specimens had shorter failure time than unsqueezed specimens. The failure time of squeezed specimens were however never shorter than the failure time for notched specimens (0.5 mm deep notch).

4.2.3 Work done in Canada

At the Industrial Materials Research Center in Canada the recovery of the pipe after squeeze-off was investigated (9-11). The holding time in the fully squeezed position had little effect on the extent of recovery (see Figure 3, the distance **h** divided by the unsqueezed diameter). The diametrical long term recovery of pipes squeezed at -20°C was higher (92 %) compared to pipes squeezed at 23°C (88%).

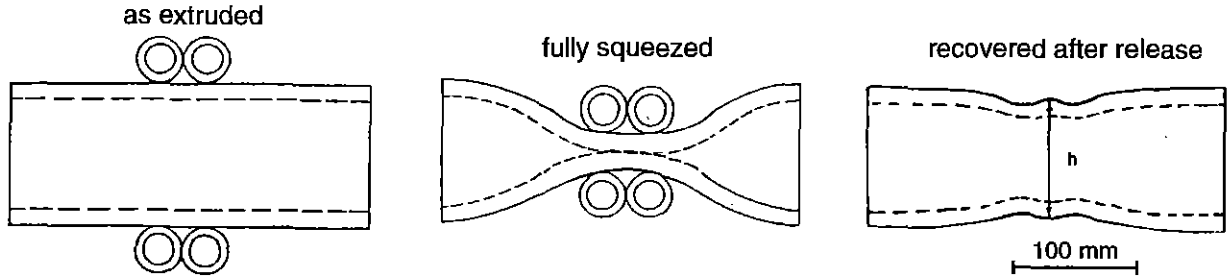


Figure 3
Squeeze-off procedure used in Canada. Double bar squeeze-off. Single bar squeeze-off tools are also used.

The compression was stopped when the force on the bars was rapidly increasing. The wall compression was approximately 18 %. The compression rate was 25 mm/min.

4.3 Direct contacts with companies

A list of the contacted companies is found on page 24. The information was collected by telephone interviews made in November 1995. For further details please take direct contact with the different companies (see page 23). The summary below is preliminary and may be revised in the final report.

4.3.1 Gas Utilities

Six Gas Utilities were contacted: British Gas, Italgas, Gaz de France, Naturgas Mittnor (Denmark), Naturgas Syd (Denmark) and Sydgas (Sweden).

The procedure used by **Sydgas** is described in detail in Appendix B. The squeeze is performed in two or three steps to ensure smooth deformation. Normally no rerounding tools are allowed, except for "catastrophic squeeze-off". They use different squeeze-off tools but one very common is equipment from Fusion Equipment in the UK.

Italgas uses no strict recommendations for squeeze-off. They have internal procedures and people are educated on squeeze-off. They have equipment from Fusion Equipment (UK), Haxe Engineering (UK) and Sensco (France). They are very careful and restrictive of using squeeze-off. All squeeze-offs are followed by rerounding. Normally they shut off the gas after squeeze off and exchange the pipe section that was squeezed. Problems have only occurred when the procedures are not followed. Italgas believes that HDPE is more sensitive to squeeze-off than MDPE.

Gaz de France has internal specifications for squeeze-off. No pipes with Ø>125 mm are squeezed. In some cases the pipes are replaced after squeeze-off. Rerounding is normally applied. They use circular bars and hydraulic tool for large diameter pipes. The wall compression is 10%.
Gaz de France performs extensive internal research on squeeze-off. According to their research pressure testing of pipes subjected to squeeze-off scatter a great deal in lifetime. It was not possible to correlate lifetime with squeeze-off parameters. The same situation holds for microscopic observations of sectioned pipes subjected to squeeze-off. Gaz de France proposes the full notch tensile creep test as the best method to evaluate "squeeze-off lifetime". Gaz de France makes own specifications and recommendations, and they buy equipment from different companies. At CERSTA at Gaz de France theoretical work is performed in order to calculate pipe damage from rheological and slow crack growth behavior. This will result in future recommendations on squeeze-off by Gaz de France.

At **Naturgas Syd** in Denmark the squeeze-off procedure is based on the procedure described in ISO/DIS 4437, and also the recommendations issued by the pipe manufacturers. The wall compression is 20 % for pipe diameters ≤250 mm and 10 % for greater diameters. Naturgas Syd does not use rerounding and only manual tools are used. No PE 100 pipes are used in Denmark today. The pipe wall thickness of a 160x14.6 mm pipe after squeeze-off was less than the requirements in the standard in DS 2131, according to a investigation performed by Naturgas Syd.

At **Naturgas Mittnor** in Denmark they use the squeeze-off procedures recommended by the pipe manufacturers (Uponor and Nordisk Wavin). The maximum wall compression is 30%. For small pipe diameters they use a manual clamp tool. For intermediate pipe diameters a manual jack and for large diameters Naturgas Mittnor has a modified electrical hydraulic tool. The largest pipe diameter is 250 mm. The squeeze-off is performed in one moment with no intermediate steps. For large diameter pipes it is sometimes necessary to apply two squeeze-offs (double squeeze) to stop the gas flow. Great attention is give to assure a slow compression rate. No rerounding is performed since it is believed to damage the pipe and also because a 4 bar overpressure will help the pipe to reround by it self after squeeze-off. After the squeeze-off the place for the squeeze-off is marked. It is not allowed to make another squeeze-off closer than 4 times the outer diameter from the previous squeeze-off location. In certain low pressure systems (e.g. 100 mbar overpressure) rerounding is performed because it is necessary to have a round pipe. The low over pressure is too low for the pipe to reexpand to its previous roundness.

British Gas has used squeeze-off for 29 years with no problems, except for the new PE 100 materials (the new third generation high density polyethylenes). The PE 100 cracks after squeeze-off and therefore it is not allowed to squeeze-off PE 100 pipes on a regular basis, only in a emergency situation. British Gas believes the PE 100 is more likely to be damage by squeeze-off at cold temperatures compared to PE 80. Less than 5 % of the new installations are performed with PE 100 pipes. No field failures caused by squeeze-off are reported within British Gas after 29 years of use.

Squeeze-off procedure at British Gas
PE-pipes in all dimensions are squeezed. The tools are manually operated (both clamp and jack tools). The wall compression is about 20 %. Sometimes oversqueeze stops are used for more than one pipe dimension and the wall compression might differ slightly from 20 %. The bars are slowly compressed in one moment with no steps, also for large diameter pipes. The largest pipe diameter they have squeezed is about 350 mm. But there is no limitation in the British Gas code-of-practice regarding squeeze-off of large pipe diameters. No rerounding tool is used since they do not believe it is important for the damage of the pipe and because the practical circumstances most often do not require a rerounding. The pipe rerounds by it self after a few days, for high pressure pipes (≥4 bar). If rerounding is used then the same squeeze-off tool is used and turned circumferentially 90° and then the bars are compressed (re-squeezed) on the pipe, which causes rerounding. It is also common practice to perform the re-squeeze several times at some axial distance from the squeeze-off and successively come more narrow to the squeeze-off. The squeeze-off is marked with tape. The next squeeze-off must not be closer than 3 pipe diameters from the first squeeze-off.

For large diameter pipes in high pressure systems (≥4 bar) two squeezes (double squeeze-off) are generally performed. The reason is that with a double squeeze-off it is possible to use a lower wall compression (e.g. 10 % instead of 20 %). British gas believes a large pipe dimension (large wall thickness) is more sensitive to squeeze-off damage than a small pipe dimension. It is also more safe to have two squeeze-offs if one should get loose. British Gas uses squeeze-off tools from Fusion Equipment and from Haxe Engineering (both in UK).

4.3.2 Pipe manufacturers

Nordisk Wavin in Denmark has a recommendation for squeeze off with PE-pipes from Wavin. According to this (11) the wall compression shall be less than 30%. It shall be at least 4 times Dy between two successive squeeze-offs. According to Nordisk Wavin there are no limitations in using squeeze-off with polyethylene pipes from Wavin.

Wirsbo Bruks, producer of PE-X pipes for gas and water distribution, have PE-X pipes that fulfills squeeze-off requirements at -50°C according to Ref 12.

4.3.3 Resin producers

Borealis does not often receive questions on squeeze-off from customers. They do not consider it as a problem since no field failures have been reported in Europe caused by squeeze-off. As long as the correct procedures and tools are used they consider a squeeze-off as a safe operation.

Elf Atochem, the resin manufacturer of Nylon 11, have made own tests on pipe deflection after squeeze-off. According to these data Nylon pipes (PA 11 also Rilsan B) have less deflection after squeeze-off than PE-pipes. Elf Atochem in Australia and IPS/AGL are contacted for further details.

4.3.4 Tool manufacturers

Fusion Equipment in UK makes squeeze-off tools for PE-pipes for diameters less than 400 mm. Both water and gas pipes may be squeezed. Their squeeze-off tools have almost not changed at all during the last 15-20 years. They are not familiar to squeeze-off with Nylon pipes. Their agent in Sweden, KWH Pipe, is careful when recommending squeeze-off, since it is believed to be harmful to the pipe material.

According to many Gas Utilities the tool manufacturers do not have any own development or research within squeeze-off of PE-pipes. The manufacturing is completely according to the specifications from the end user or the pipe manufacturer. Sometimes the Gas Utility also modifies the tools.

4.3.5 Others

According to the **Nordiska Plaströrgruppen** in Sweden squeeze-off is not used for water or waste PE-pipes in Sweden. However, according to utilities in Denmark and England squeeze-off is sometimes used with pipes for water distribution.

4.4 Standards for checking squeeze-off of PE-pipes

Below a few typical standards have been rewieved regarding procedure to check squeeze-off with PE-pipes. Please note that the standards are not instructions on how to perform field squeeze-offs, it is a procedure to make quality control of pipes subjected to a severe squeeze-off. These standards are subjected to continuos revision.

ISO/DIS 4437 (annex H) (14) specifies the following squeeze-off technique: The apparatus and the squeeze-off equipment shall be as recommended by the pipe manufacturer and the code of practice. The specimens shall be conditioned for at least 10 h at 0°C and then squeezed for at least 60 min. Then the pipe shall be pressure tested at 80°C in water for 165 h at 4.6 or 5.5 MPa.

ISO/DIS 4437 also specifies squeeze-off with PE-X (crosslinked polyethylene) pipes (15). The pipes are conditioned at -50°C. The wall compression is 20% for Ø<250 mm and 10 % for other diameters. The bar diameter is also larger for larger pipe diameter. The pipe shall be squeezed for 15 min. The duration of the pressure test is 165 h at 95°C and 3.8-6.0 MPa depending on the resin classification.

prEN 12106:1995 (16) for polyethylene pipes is very similar to ISO/DIS 4437 for PEX. The only difference is the conditioning temperature, 0°C, and the pressure testing temperature, 80°C.

British Gas specifications (17) is similar to ISO but also specifies that wall compression shall be 30 %. The pressure test duration time is 1 000 h at 80°C and 4.0 MPa.

In the **Danish standard DS 2131.2** (18) the wall compression shall be according to the specifications from the pipe manufacturer. The duration of the pressure test is 170 h at 80°C and 4.0 MPa.

The **Swedish standard SS 3470** (19) also specifies the bar diameter at squeeze-off. The pipe is conditioned for 10 h at minus 5 to minus 10°C prior to squeeze-off. The duration of the pressure test is 170 h at 80°C and 4.6 MPa.

4.5 Conclusions from the literature survey

Battelle has probably done the most extensive work within squeeze-off of PE-pipes. However interesting information was also obtained from the industry. This information can by summarized as follows:

- There are no reported field failures of PE-pipes caused by squeeze-off in Europe.
- The most important parameter for squeeze-off is the wall compression. It is not advisable to compress the pipe walls more than 30 %.
- Squeeze-off at low temperatures does not necessarily cause more damage to the pipes than at higher temperatures.
- Rerounding does not cause additional damage to the pipe wall as long as the wall compression is less than 30 %.
- It is very important to have stops on the squeeze-off tool to prevent oversqueezing.
- The release of the bars at low speed is more important than the compression at low speed.
- There is no tool development of squeeze-off tools. The Gas Utilities modifies the tools them selves.
- British Gas does not allow squeeze-off on a regular basis with their recently installed PE 100 gas pipes.

5 Experimental program

5.1 Introduction

The goal of the experimental program is to generate long term data by using two testing conditions, one rapid qualitative test and one lifetime test. Hydrostatic pressure testing was performed with water as the internal medium and air or detergent (stress cracking environment) as the external medium. Testing in detergent is the rapid qualitative test while testing in air is the lifetime test, which on the other hand is more time consuming.

5.2 Materials

Two different pipe dimension were used 160x14.6 mm and 63x5.8 mm. The pipes were made by Nordisk Wavin A/S with Finathene 3802 YCf resin (MDPE, PE 80). Details of the pipes are presented in Appendix A.

5.2.1 Squeeze-off procedure

Squeeze-off was performed in Åstorp and documented by Tomas Tränkner. After squeeze-off the pipes were transported directly to Studsvik by Tomas Tränkner. The pipes were squeezed by using two different squeeze-off procedures. The procedures follows the current routines used by Sydgas in Sweden (20). The squeezing was separated in one "normal" and one "catastrophic" squeeze-off. The "catastrophic" squeeze-off is more rapid than the "normal" squeeze-off procedure. The squeeze-off is presented in detail in Appendix B. The squeeze-off was performed on May 9-10, 1995, in Åstorp, Sweden. The outdoor temperature was between 6 and 14°C during the two days. Figure 4 shows the set-up during squeeze-off.

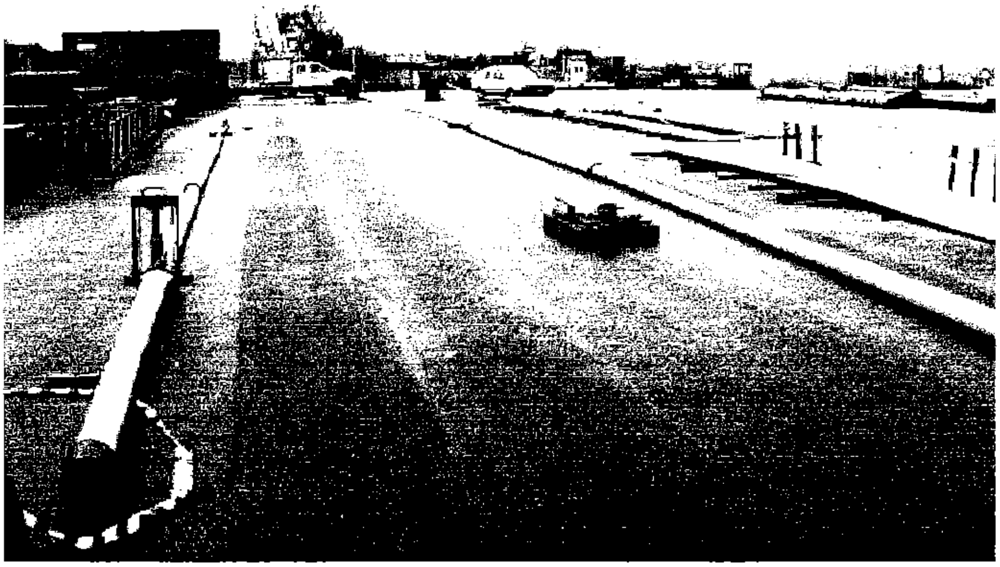


Figure 4
Overview of the set-up for squeeze-off in Åstorp in Sweden. The pipes were welded with electrofusion fittings. The pipes were conditioned for 24 h at 3.8 bar nitrogen overpressure. The temperature was 6-14°C. In total 13 squeeze-offs were made for each pipe dimension (Ø=63 mm and Ø=160 mm).

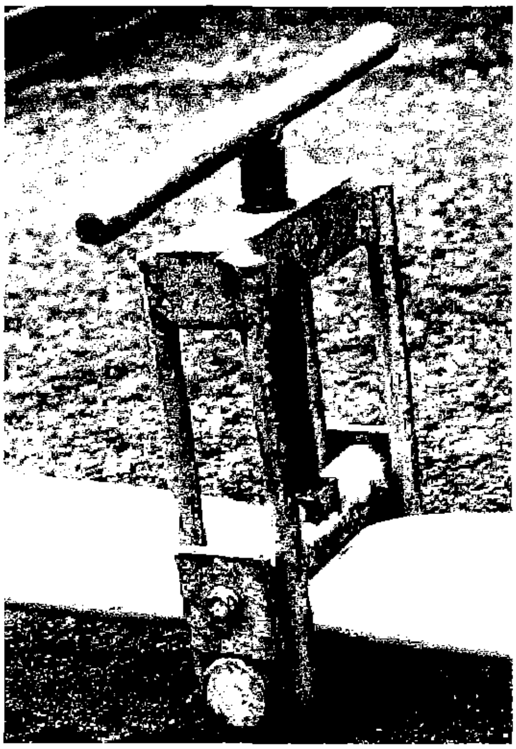


Figure 5
Squeeze-off tool for 63x5.8 mm PE-pipes. The Figure shows when the bars are in the fully squeezed position. The pipe was squeezed for 30 min.

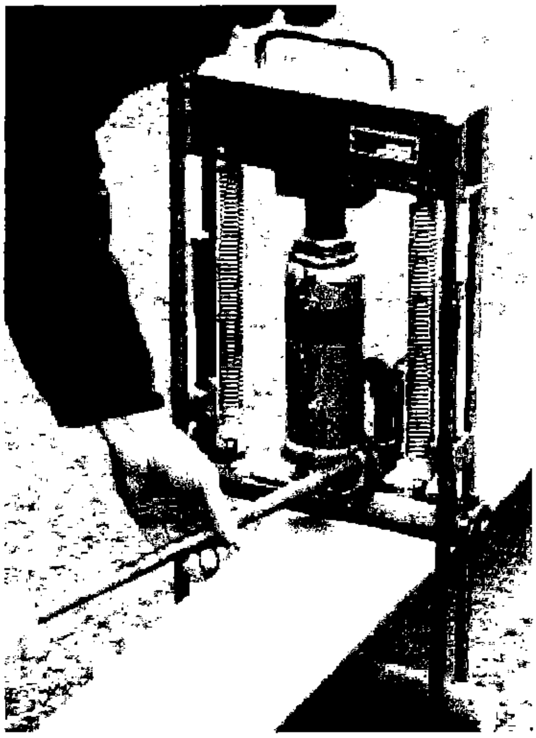


Figure 6
Squeeze-off tool for 160x14.6 mm PE-pipes. The Figure shows when the bars are in the upper position. The pipe was squeezed for 45 min.

Figure 5 and 6 shows two pictures of the squeeze-off tools. In Figure 5 a screw driven tool is used for 63x5.8 mm pipes. Figure 5 shows the tool in the bottom position. At the upper bar the stops are mounted. Figure 6 shows the hydraulic jack for 160x14.6 mm pipes prior to squeeze-off.

Two stops mounted on the upper bar on the jack tool stopped the bars to be compressed to much. The wall compression was 19 % for the Ø=63 mm pipes and 14 % for the Ø=160 mm pipes. See section 4.2.1 for the definition of wall compression. According to most specifications the wall compression should not exceed 30 % to avoid damage of the pipe. Figure 7 shows a detail of the stops when the jack tool is completely compressed. Figure 8 shows a rerounding tool for Ø=63 mm pipes. Figure 9 shows the remaining deformation after a "normal" squeeze-off with no rerounding tool. Figure 10 shows the same pipe dimension after a catastrophic squeeze-off when a rerounding tool was used.

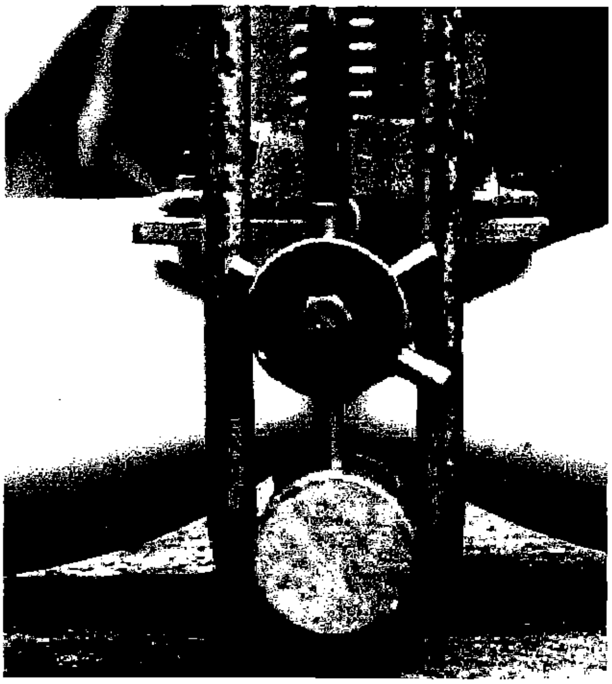


Figure 7
Squeeze-off tool for Ø=160 mm pipes. The Figure shows a detail of the stops. The bars are in their most compressed position, corresponding to a wall compression of 14 %. The bottom position was kept for 45 min.

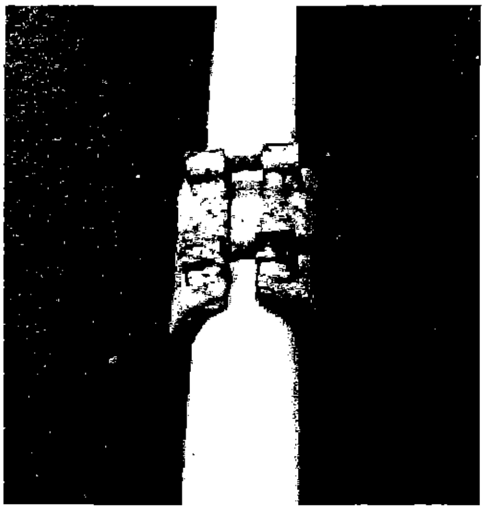


Figure 8
Rerounding tool for a Ø=63 mm pipe prior to rerounding. The rerounding was kept for 5 min.

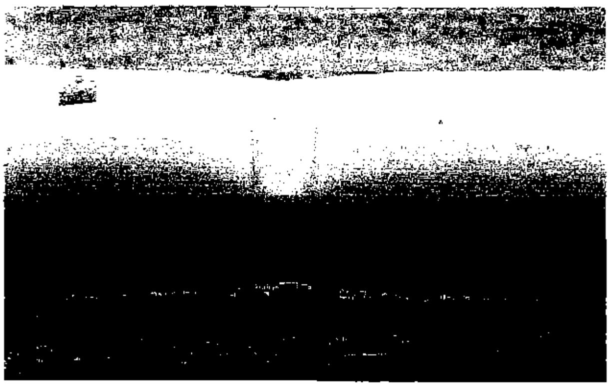


Figure 9
Squeeze-off of a Ø=160 mm PE-pipe using "normal" procedure with no rerounding. Remaining deformation immediately after the removal of the tsqueeze-off tool.

Figure 10
Squeeze-off of a Ø=160 mm PE-pipe using "catastrophic" procedure with rerounding. Remaining deformation immediately after the removal of the rerounding tool.

5.3 Experimental approach

Hydrostatic pressure testing was performed in order to evaluate the lifetime of PE-pipes subjected to squeeze-off. The hydrostatic pressure testing equipment was designed by Studsvik. The principles are shown in Figure C.1. The pressure accuracy is better than ±2. The temperatures were controlled within ±1°C. Testing was carried out with water filled pipes, the external environment was either detergent or air. The detergent was 2 % solution of BASF Lutensol FA12 in water. The general testing conditions followed ISO 1167-1973.

5.3.1 Why use hydrostatic pressure testing in Lutensol?

Hydrostatic pressure testing in Lutensol (internally water) at 95°C was used for a rapid qualitative evaluation of the sensitivity to brittle failures (defect content or squeeze-off damage) of pipes subjected to squeeze-off. Lutensol is accelerating the time to obtain brittle failures compared to testing in water or air. The acceleration factor depends on the defect content (and also any potential squeeze-off damage). Generally speaking the reduction factor will be 10-100 times by using detergent.

5.3.2 Why use hydrostatic pressure testing in air?

Pressure testing in air at 80°C was performed in order to check the lifetime of pipes subjected to squeeze-off. Testing in air (internally water) is more related to field conditions compared to testing in Lutensol. Therefore the results from testing in air is of great value for lifetime estimations, however the necessary testing times may be significantly longer compared to testing in detergent.

5.4 Results from hydrostatic pressure testing

5.4.1 Introduction to hydrostatic pressure testing

During service a plastic pipe is exposed both to loading factors and environmental factors, and these will control the lifetime of the pipes. The lifetime for different internal pressures is normally referred to as the creep rupture curve. The creep rupture curve of polyethylene pipes may be divided into three stages; Stage I, II and III depending on the failure mechanisms, see Figure 11.

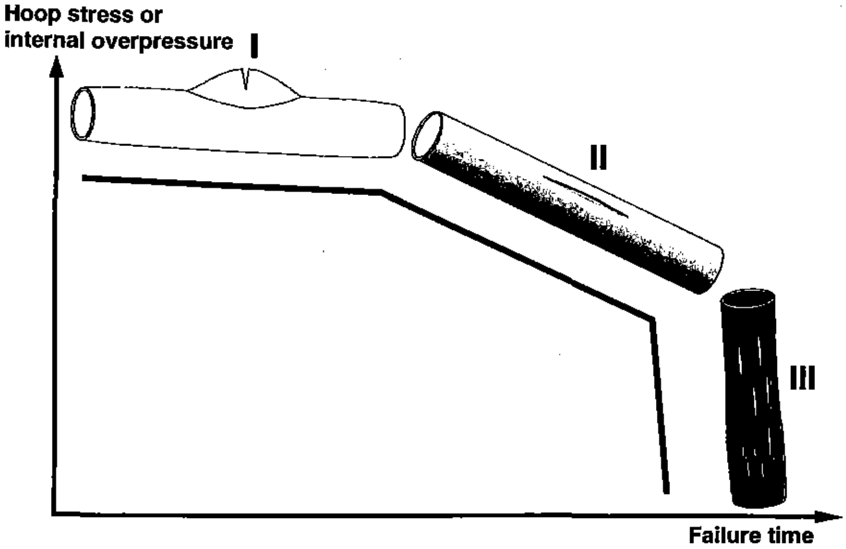


Figure 11
Schematic creep rupture curve for plastic pipes (as observed at higher temperatures).

Stage I
The Stage I failures are typically ductile due to a too high pressure for the pipe wall. If a large defect or damage is present in the pipe wall brittle failures may also occur within Stage I.

Stage II
At Stage II the slope of the creep rupture curve is changed to become more steep. Within Stage II brittle failures dominate. The failures are initiated at defects or damage points in the pipe wall. Stage II failures are not caused by chemical degradation of the pipe material.

Stage III
Within Stage III the slope of the creep rupture curve is almost vertical. The failure time is nearly independent of the internal pressure due to chemical degradation of the pipe material.

Stage III is of great importance for hot water pipes. For plastic pipes for gas distribution Stage I and II is of the greatest importance, as long as any chemical degradation is insignificant.

The hydrostatic pressure testing program has one short term test (testing in Lutensol) and one long term test (testing in air). The short term test is chosen in order to give an indication of the Stage II within one year of testing (95°C with internally water and externally Lutensol). The long term test is focused to give an indication of the Stage II lifetime within 1-3 years of testing. The long term testing is performed at 80°C with internally water and externally air.

5.4.2 Hydrostatic pressure testing in Lutensol

The Lutensol is a water solution with 2 % BASF Lutensol FA12 (detergent). For most plastic pipes the time to Stage II (brittle failures) is greatly reduced when the test is performed in Lutensol. Sometimes the time reduction factor can be 10 or more.

The results from pressure testing in Lutensol are presented in Tables D.1-D.2 and in Figures 12 and 13. In total 14 pipes have been started at 95°C in Lutensol (internally water).

Conclusions regarding 63 x 5.8 mm pipes

All pipes except one are still under test, with a testing time of more than 19 824 h.

Reference pipes - not subjected to squeeze-off
All pipes are still under test, with a testing time of more than 19 872 h. The reference pipes have a very good stress crack resistance. Stage II will most likely not occur before 50 years at 20°C.

Pipes subjected to normal squeeze-off
All pipes are still under test, with a testing time of more than 19 872 h. It is likely to belive that the normal squeeze-off does not shorten the lifetime of the pipes to less than 50 years at 20°C.

Pipes subjected to catastrophic squeeze-off
One brittle faliure has occurred atfer 16 813 h. But this faliure was probably not caused by the squeeze-off. Therefore it is likely to believe that the catastrophic squeeze-off does not shorten the lifetime of the pipes to less than 50 years at 20°C.

Conclusions regarding 160 x 14.6 mm pipes

All the large diameter pipes have failed. The longest failure time was 15 269 h. The results so far are summarized below.

Reference pipes - not subjected to squeeze-off
Both the large diameter pipes have failed. The average failure time was 10 881 h. This indicates that the reference pipes have an acceptable time to Stage II. A few secondary crack can be seen at the inside pipe wall for both the tested pipes. The failure and the fracture surface of pipe specimen 1048-17 are shown in figures E.1 - E.2. The crack was initiated at the inside pipe wall.

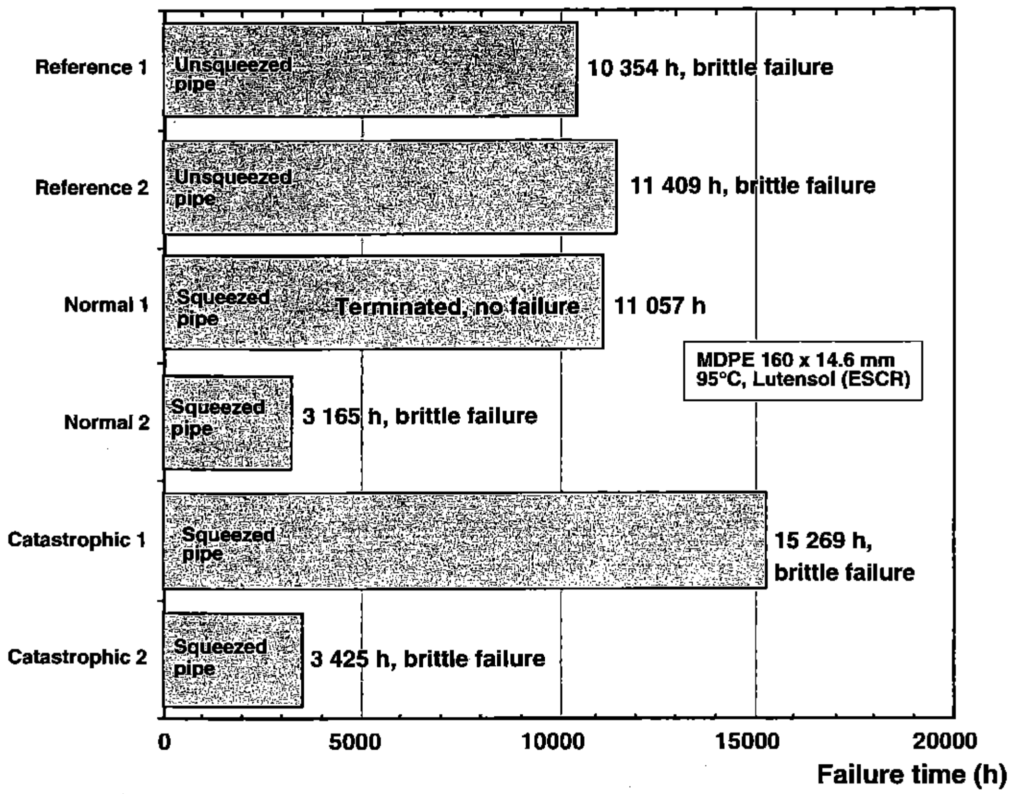


Figure 12
Hydrostatic pressure testing of 160x14.6 mm MDPE-pipes at 95 °C with Lutensol as the external medium and water as the internal medium.

Pipes subjected to normal squeeze-off
One of the normal squeezed pipes failed at 3 165 h and the other one was terminated after 11 057 h. The failed pipe, 1048-7, had many secondary cracks at the inside pipe wall. The failure was located in the same clockwise position as the squeeze-off zone but not very close in axial direction to the squeeze-off zone. Details of the failure is shown in Figure E.3.

Pipes subjected to catastrophic squeeze-off
The catastrophic squeezed pipes failed at 3 425 h and 15 269 h. One of the failed pipe had no secondary cracks at the inside pipe wall and the other one only a few. The pipe with the shortest failure time had a failure that was located in the same clockwise position as the squeeze-off zone but not very close in axial direction to the squeeze-off zone. Details of the failure are presented in figures E.4 - E.6. As can be seen from the photo in Appendix E.5 the failure was initiated by a particle or defect near the outer wall of the pipe. It is not possible to judge what role the squeeze-off played in causing the failure.

The catastropic squeezed pipe with the longest failure time had a failure located far from the squeeze-off zone. It is likely to belive that the failure was not caused by the squeeze-off.

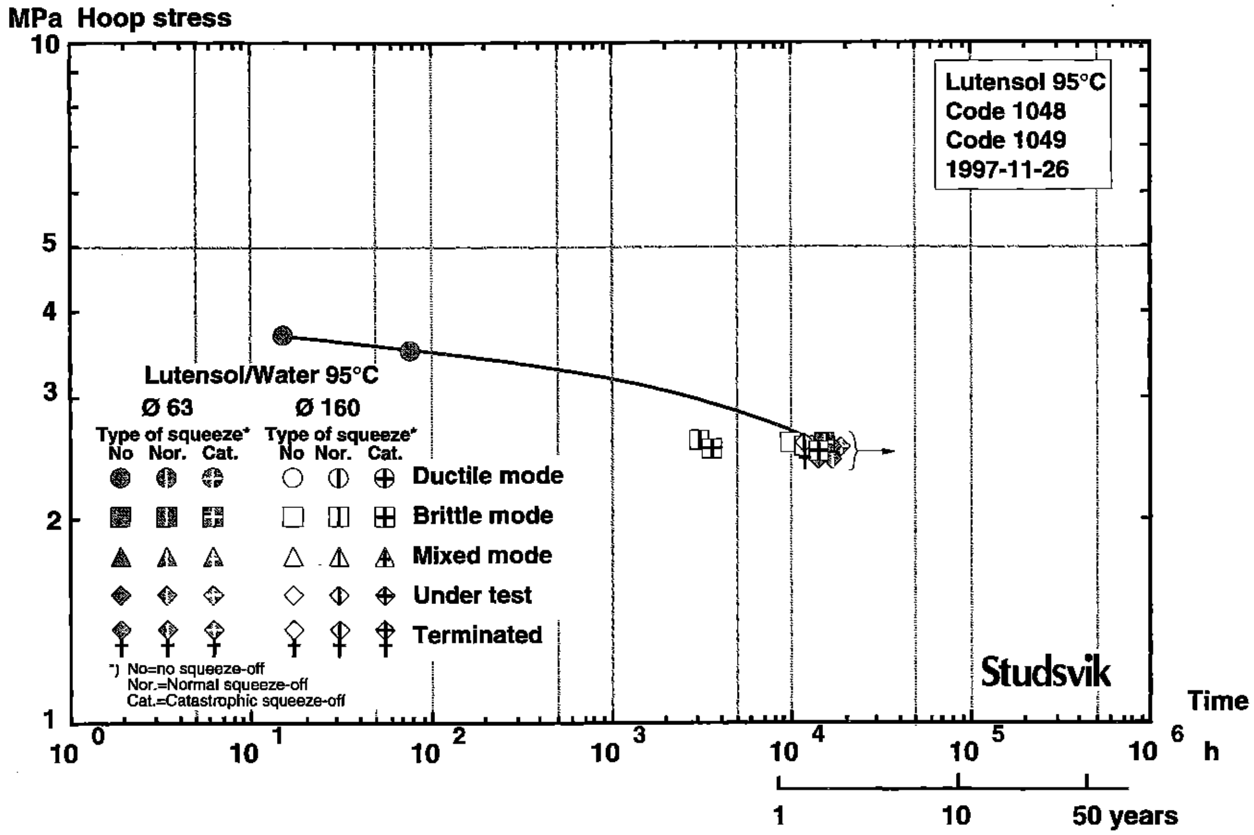


Figure 13
Hydrostatic pressure testing of 63x5.8 mm and 160x14.6 mm PE-pipes subjected to squeeze-off. The testing was performed at 95 °C with internally water and externally 2 % Lutensol FA12.

Summary of the results from testing in Lutensol

* The Ø=63 mm pipes have probably a longer time to Stage II than the Ø=160 mm pipes (this is only valid for the investigated pipes, other pipes may behave in a different way depending on resin, extrusion, etc.).
* For the large pipes the premature failures of pipes subjected to squeeze-off may indicate a shorter time to Stage II due to the squeeze-off.
* Some of the Ø=160 mm pipes have many secondary cracks at the inside. The great number and the big size of the secondary cracks are unusual.
* The catastrophic squeeze-off does not seem to be very critical to the pipes.
* For the Ø=63 mm pipes it is likely to belive that the squeeze-off does not shorten the lifetime of the pipes.

5.4.3 Hydrostatic pressure testing in air at 80°C

The results from pressure testing in air are presented in Tables D.3-D.4. In total 14 pipes have been started at 80°C in air (internally water). The longest testing time today is 20 688 h. Only Stage I failures of unsqueezed pipes are obtained, see Figure 14. These failures were expected and used to determine the appropriate testing pressure for pipes subjected to squeeze-off. The Stage I creep rupture curve was extrapolated to 1 000 h. 80 % of the stress, corresponding to a 1 000 h failure time, was selected for the pipes subjected to squeeze-off. The testing pressure at 80°C was 7.6 bars (hoop stress 3.6 MPa).

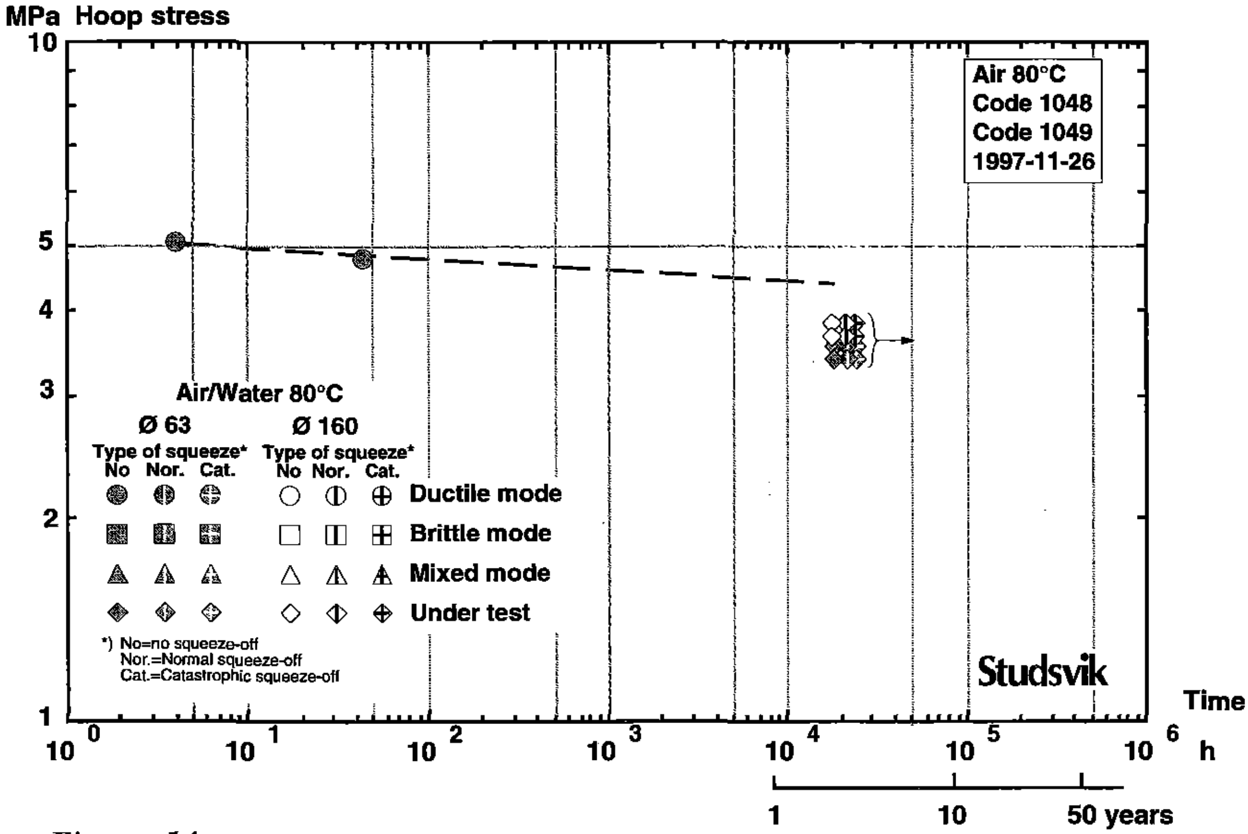


Figure 14
Hydrostatic pressure testing of 63x5.8 mm and 160x14.6 mm PE-pipes subjected to squeeze-off. The testing was performed at 80°C with internally water and externally air.

Good results have been obtained from testing in air at 80°C. It is not possible to see any loss in lifetime due to the squeeze-off. If the most conservative thumb of rule of lifetime extrapolation (e.g. the failure time is at least two times longer if the testing temperature is lowered with 10°C) is applied on testing time 20 688 h, the expected failure time at 20°C would be at least 50 years.

6 Conclusions

Conclusions from the literature study:

- There are no reported field failures of PE-pipes caused by squeeze-off in Europe.
- The most important parameter for squeeze-off is the wall compression. It is not advisable to compress the pipe walls more than 30 %.
- Squeeze-off at low temperatures does not necessarily cause more damage to the pipes than at higher temperatures.
- Rerounding does not cause damage to the pipe wall as long as the wall compression is less than 30 %.
- It is very important to have stops on the squeeze-off tool to prevent oversqueezing.
- The release of the bars at low speed is more important than the compression at low speed.
- There is no tool development of squeeze-off tools. The Gas Utilities modifies the tools them selves.
- British Gas does not allow squeeze-off of their recently (1995) installed PE 100 gas pipes.

Conclusions from hydrostatic pressure testing:

- The Ø=63 mm pipes have probably a longer time to Stage II than the Ø=160 mm pipes (this is only valid for the investigated pipes, other pipes may behave in a different way depending on resin, extrusion, etc.).
- For the large pipes the premature failures of pipes subjected to squeeze-off may indicate a shorter time to Stage II due to the squeeze-off.
- Some of the Ø=160 mm pipes have many secondary cracks at the inside. The great number and the big size of the secondary cracks are unusual.
- The catastrophic squeeze-off does not seem to be very critical to the pipes.
- For the Ø=63 mm pipes the squeeze-off seems not to have any critical effect on the lifetime of the pipes.
- The lifetime of the pipes subjected to squeeze-off is most likely at least 50 years at 20°C and 4 bar.

Acknowledgments

Olle Johansson and Per-Arne Persson at Sydgas are thanked for performing the squeeze-off in Åstorp in Sweden.

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Table A.1

Investigated pipe materials. After squeeze-off of the pipes at Sydgas in Åstorp, the pipes were shipped by Tomas Tränkner to Studvik from Sydgas.

Ø=160 mm pipes

Pipe manufacturer
Nordisk Wavin A/S

Resin Manufacturer
FINA, Finathene 3802 YCf lot nr 4/2227

Pipe dimension
160 x 14.6 mm

Pipe marking
PN 4 (Wavin) =2=DS=2131.2=SIS 379=GAS= =94/37/7= =648240= = meter marking = ==GAS ==PEM/F = =160x14.6 =

Delivery date to Studsvik
Directly after squeeze-off the pipes were transported by Tomas Tränkner to Studsvik 1995-05-11.

Studsvik code
1048-

Ø=63 mm pipes

Pipe manufacturer
Nordisk Wavin A/S

Resin Manufacturer
FINA, Finathene 3802 YCf

Pipe dimension
63 x 5.8 mm

Pipe marking
PN 4 (Wavin) =2=DS=2131.2=SIS 379=GAS= =93/35/3= =646510= = meter marking = ==GAS ==PEM/F = =63x5.8 =

Delivery date to Studsvik
1995-05-11. The pipes were first delivered from Nordisk Wavin (Denmark) to Studsvik (Sweden) 1995-03-19 and then shipped to Åstorp (Sweden) 1995-03-23. Directly after squeeze-off the pipes were transported by Tomas Tränkner to Studsvik 1995-05-11.

Studsvik code
1049-

Squeeze-off with PE-pipes at Åstorp in Sweden

Date: May 9-10, 1995
Place: Sydgas, Åstorp
Participants: Olle Johansson, Sydgas
Gert Owe Persson, Sydgas
Tomas Tränkner, Studsvik Material AB

Introduction

The squeeze-off was performed with two pipe dimensions, Ø=160 and Ø=63 mm (SDR 11). The pipes were joined with electrofusion fittings each 10 meter, in total 40 m of each pipe dimension. The pipes were conditioned at 3.8 bar for 24 h prior to squeeze-off. The temperature during conditioning was 6-10°C. The temperature during squeeze-off was 11°C and rain. On May 10 it was 6.5°C in the morning and 10°C at 13.00 o´clock with temporary rain showers. The peak temperature during the day was 14°C. About 35 photos were taken during the squeeze-off. In Appendix B.4 the squeeze-off procedure is shown in a diagram.

The squeeze-off was performed with two types of squeeze-off techniques (normal and catastrophic) on both pipe dimensions. Those are the current routines for squeeze-off used at Sydgas. The routines are briefly described in Ref 20. The first squeeze-off was normal and the subsequent was catastrophic. Squeeze-off was performed at each 2nd meter. In total 13 squeeze-offs were performed with each pipe diameter.

Squeeze-off tools

With pipe dimensions 63x5.8 mm (code 1049-), a clamp tool was used for squeeze-off, made by Fusion Equipment, Dronfield Derby, England. The bar diameter was 31.7 mm. The minimum distance between the bars was 9.3 mm. The maximum wall compression would then be 19 % (0.81x2t). The deformation rate at the final part of the squeeze-off was slower than the first part. One squeeze-off is also divided into several minor steps when taking a new hand grip. If the squeeze-off tool was not perfectly centered along the pipe one bar end reached the bottom position before the other one. It is also possible that the squeeze-off tool become out-of-line during the squeeze-off due to torque of the tool. There were stops mounted on the lower bar to limit the squeeze-off to a certain maximum rate.

For pipe dimension 160x14.6 mm (code 1048-) a jack was used for the squeeze-off. The jack was manually controlled. The squeeze-off tool had the following markings: Fusion equipment, Dronsfield England, M-ST/180, PR 3313/486. The bar diameter was 51 mm and the minimum distance between the bars was 25 mm. The maximum wall compression was 14 %. When reaching the bottom position two screws were screwed so that the stops were fixed keeping the bars in the bottom position. The force against the stops decreased as a function of time. During removal of the bar the jack was decomprimated and two springs lifted the upper bar. The course of event was quite rapid. During the last six squeeze-offs the jack was leaking oil which resulted in a somewhat slower compression rate than the first 6 squeeze-offs. There were stops mounted on the lower bar to limit the squeeze-off to a certain maximum rate.

Normal squeeze-off of 63x5.8 mm PE-pipes (code 1049-)

The squeeze-off was performed with a manually operated clamp tool. The squeeze-off was performed in two steps as follows:

1 Tightening of the bars until 19 mm was remaining between the stops and the lower bar. Time elapsed was 35 s.
2 Waiting for 5 min.
3 Tightening or the bars until the stops met the lower bar. Time elapsed was 40 s.
4 Waiting for 5 min.
5 Release the bars until 19 mm was remaining between the stops and lower bar. Time elapsed 40 s.
6 Waiting for 5 min.
7 Complete release of the bars and removal of the tool from the pipe.

Catastrophic squeeze-off of 63x5.8 mm PE-pipes (code 1049-)

Squeeze-off was performed in one moment with no intermediate steps. The bars were compressed immediately. After release the pipe was rerounded by a special tool. The rerounding tool was two metal parts with the same inner diameter as the pipe. Four threaded bolts were used to squeeze the rerounding tool on the pipe.

1 Tightening of the bars to the bottom position. Time elapsed 40 s.
2 Waiting for 30 min.
3 Complete release of the bars and removal of the tool from the pipe.
4 Application of the rerounding tool. The tightening of the rerounding took about 5 min.
5 Waiting for 5 min.
6 Removal of the rerounding tool. Time elapsed was 60 s.

Normal squeeze-off of 160x14.6 mm PE-pipes (code 1048-)

A jack maneuvered squeeze-off tool was used.

1 Tightening of the bars until 50 mm was remaining between the stops and the lower bar. Time elapsed was 60 s.
2 Waiting for 5 min.
3 Tightening of the bars until 30 mm was remaining between the stops and the lower bar. Time elapsed was 40 s.
4 Waiting for 5 min.
5 Tightening of the bars until the stops met the lower bar. Time elapsed was 40 s. *Due to some leakage of oil in the jack the compression of the last 2 mm was somewhat slower. The additional time due to leaked to reach complete tightening was less than 60 s.*
6 Waiting for 45 min.
7 Release the bars until 30 mm was remaining between the stops and lower bar. Time elapsed 5 s.
8 Waiting for 5 min.
9 Release the bars until 50 mm was remaining between the stops and lower bar. Time elapsed 5 s.
10 Waiting for 5 min.
11 Complete release of the bars and removal of the tool from the pipe. Time elapsed 5 s.

Catastrophic squeeze-off of 160x14.6 mm PE-pipes (code 1048-)

Squeeze-off was performed in one moment with no steps. The bars were compressed immediately by using a jack. After release the pipe was rerounded by a special tool. The rerounding tool was two metal parts with the same inner diameter as the pipe. Four threaded bolts were used to squeeze the rerounding tool on the pipe.

1. Tightening of the bars to the bottom position. Time elapsed 120-180 s. *Due to some leakage of oil in the jack the compression of the last 2 mm was somewhat slower. The additional time due to leaked to reach complete tightening was less than 60 s.*
2. Waiting for 45 min.
3. Complete release of the bars and removal of the tool from the pipe. Time elapsed 10 s.
4. Application of the rerounding tool. The tightening of the rerounding took about 7 min.
5. Waiting for 10 min.
6. Removal of the rerounding tool, time elapsed 60-120 s.

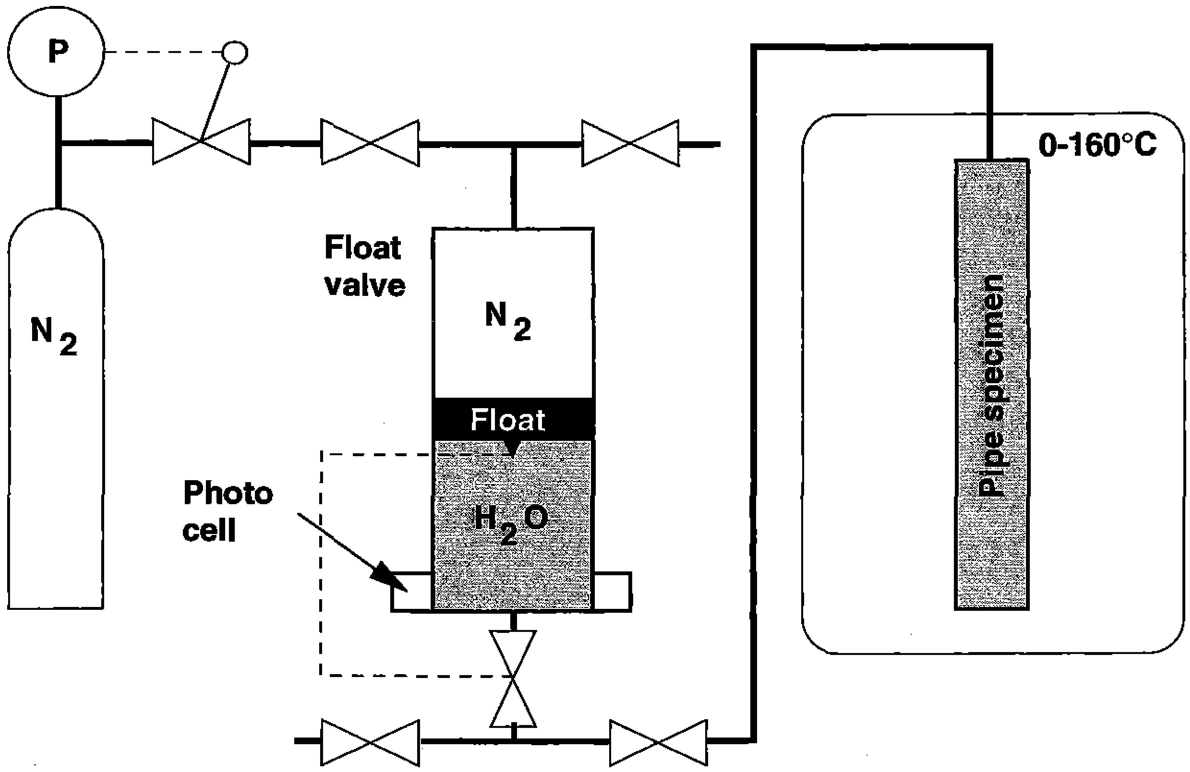

Figure C.1
Schematic diagram of the pressure testing equipment. The nitrogen is led via a pressure regulator to one or more float valves, where the transfer to water as the pressurizing medium occurs. The pipe specimen can be held in a water or detergent bath or heating cabinet.

Table D.1

Hydrostatic pressure testing at 95°C of a yellow, 63 x 5.8 mm, medium density pipe grade by using the detergent Lutensol FA (2 %) as the external and water as the internal test medium. Studsvik internal pipe code is 1049.

Test laboratory:	Studsvik Polymer AB
Test method:	ISO 1167-1973
Test medium (internal/external):	Water/lutensol
Conditioning time:	3 hours
Fittings:	Beulco
Nominal pipe dimension:	63 x 5.8 mm
Pipe length (total/free):	350/500 mm
Situation per:	1997-11-26

Specimen (Studsvik code)	Temp °C	Start	$t^{1)}$ mm	$D^{2)}$ mm	$p^{3)}$ MPa	$\sigma^{4)}$ MPa	Failure time h	Failure mode	Remarks
1049-16	95	950704	6.16	63.25	0.804	3.73	15	Ductile	5)
1049-17	95	950704	6.17	63.25	0.765	3.54	79	Ductile	5)
1049-5	95	950821	6.10	63.30	0.569	2.67	->		>19 872 h, 6)
1049-6	95	950821	6.10	63.30	0.569	2.67	16 813	Brittle	7,8)
1049-7	95	950821	6.14	63.30	0.569	2.65	->		>19 872 h, 6)
1049-20	95	950821	6.14	63.30	0.569	2.65	->		>19 872 h, 5)
1049-21	95	950821	6.16	63.30	0.569	2.64	->		>19 872 h, 5)
1049-8	95	950821	6.17	63.30	0.569	2.63	->		>19 872 h, 7)

1) Minimum wall thickness
2) Maximum mean outside diameter
3) Internal over pressure
4) Circumferential stress (hoop stress)
5) Reference pipe, not subjected to squeeze-off
6) "Normal" squeeze-off
7) "Catastrophic" squeeze-off
8) The failure was located 50 mm from the upper fitting

Table D.2

Hydrostatic pressure testing at 95°C of a yellow, 160 x 14.6 mm, medium density pipe grade by using the detergent Lutensol FA (2 %) as the external and water as the internal test medium. Studsvik internal pipe code is 1048.

Test laboratory:	Studsvik Polymer AB
Test method:	ISO 1167-1973
Test medium (internal/external):	Water/lutensol
Conditioning time:	4 hours
Fittings:	Hammel
Nominal pipe dimension:	160 x 14.6 mm
Pipe length (total/free):	800/620 mm
Situation per:	1997-11-26

Specimen (Studsvik code)	Temp °C	Start	t1) mm	D2) mm	p3) MPa	σ4) MPa	Failure time h	Failure mode	Remarks
1048-5	95	950719	15.30	160.90	0.549	2.61	11 057	Terminated	6, 10)
1048-7	95	950719	15.34	160.90	0.549	2.61	3 165	Brittle	6, 8)
1048-8	95	950719	15.30	160.90	0.549	2.61	15 269	Brittle	7, 12)
1048-16	95	950719	15.33	160.90	0.549	2.61	10 354	Brittle	5, 11)
1048-6	95	950719	15.40	160.90	0.549	2.59	3 425	Brittle	7, 9)
1048-17	95	950719	15.46	160.90	0.549	2.58	11 409	Brittle	5, 11)

1) Minimum wall thickness
2) Maximum mean outside diameter
3) Internal over pressure
4) Circumferential stress (hoop stress)
5) Reference pipe, not subjected to squeeze-off
6) "Normal" squeeze-off
7) "Catastrophic" squeeze-off
8) Failure 120 mm from the "squeeze-off ear" in the same clock wise position as the "squeeze-off ear". Many internal secondary cracks.
9) Failure 130 mm from the "squeeze-off ear" in the same clock wise position as the "squeeze-off ear". No visible secondary cracks. The failure was initiated by a defect.
10) The pipe was terminated after 11 057 h of testing. Secondary cracks were observed at the inside pipe wall.
11) The failure occurred at the central part of the pipe specimen. Only a few internal secondary cracks.
12) The failure was located between the squeeze-off zone and one pipe end. It was not located in the same clockwise position.

Table D.3

Hydrostatic pressure testing at 80°C of a yellow, 63 x 5.8 mm, medium density pipe grade by using air as the external and water as the internal test medium. Studsvik internal pipe code is 1049.

Test laboratory:	Studsvik Polymer AB
Test method:	ISO 1167-1973
Test medium (internal/external):	Water/Air
Conditioning time:	3 hours
Fittings:	Beulco
Nominal pipe dimension:	63 x 5.8 mm
Pipe length (total/free):	350/310 mm
Situation per:	1997-11-26

Specimen (Studsvik code)	Temp °C	Start	t 1) mm	D 2) mm	p 3) MPa	σ 4) MPa	Failure time h	Failure mode	Remarks
1049-14	80	950704	6.12	63.25	1.079	5.03	4	Ductile	5)
1049-15	80	950704	6.14	63.25	1.030	4.79	44	Ductile	5)
1049-1	80	950724	6.11	63.3	0.785	3.67	->		>20 544 h, 6)
1049-4	80	950724	6.12	63.3	0.785	3.67	->		>20 544 h, 7)
1049-2	80	950724	6.15	63.3	0.785	3.65	->		>20 544 h, 7)
1049-18	80	950724	6.15	63.3	0.785	3.65	->		>20 544 h, 5)
1049-19	80	950724	6.18	63.3	0.785	3.63	->		>20 544 h, 5)
1049-3	80	950724	6.18	63.3	0.785	3.63	->		>20 544 h, 6)

1) Minimum wall thickness
2) Maximum mean outside diameter
3) Internal over pressure
4) Circumferential stress (hoop stress)
5) Reference pipe, not subjected to squeeze-off
6) "Normal" squeeze-off
7) "Catastrophic" squeeze-off

Table D.4

Hydrostatic pressure testing at 80°C of a yellow, 160 x 14.6 mm, medium density pipe grade by using air as the external and water as the internal test medium. Studsvik internal pipe code is 1048.

Test laboratory:	Studsvik Polymer AB
Test method:	ISO 1167-1973
Test medium (internal/external):	Water/air
Conditioning time:	4 hours
Fittings:	Hammel
Nominal pipe dimension:	160 x 14.6 mm
Pipe length (total/free):	800/620 mm
Situation per:	1997-11-26

Specimen (Studsvik code)	Temp °C	Start	$t^{1)}$ mm	$D^{2)}$ mm	$p^{3)}$ MPa	$\sigma^{4)}$ MPa	Failure time h	Failure mode	Remarks
1048-14	80	950718	15.15	160.90	0.765	3.68	->		>20 688 h, 5)
1048-1	80	950718	15.20	160.90	0.765	3.67	->		>20 688 h, 6)
1048-4	80	950815	15.24	160.90	0.765	3.66	->		>20 016 h, 7)
1048-15	80	950718	15.23	160.90	0.765	3.66	->		>20 688 h, 5)
1048-2	80	950718	15.30	160.90	0.765	3.64	->		>20 688 h, 7)
1048-3	80	950718	15.44	160.90	0.765	3.60	->		>20 688 h, 6)

1) Minimum wall thickness
2) Maximum mean outside diameter
3) Internal over pressure
4) Circumferential stress (hoop stress)
5) Reference pipe, not subjected to squeeze-off
6) "Normal" squeeze-off
7) "Catastrophic" squeeze-off

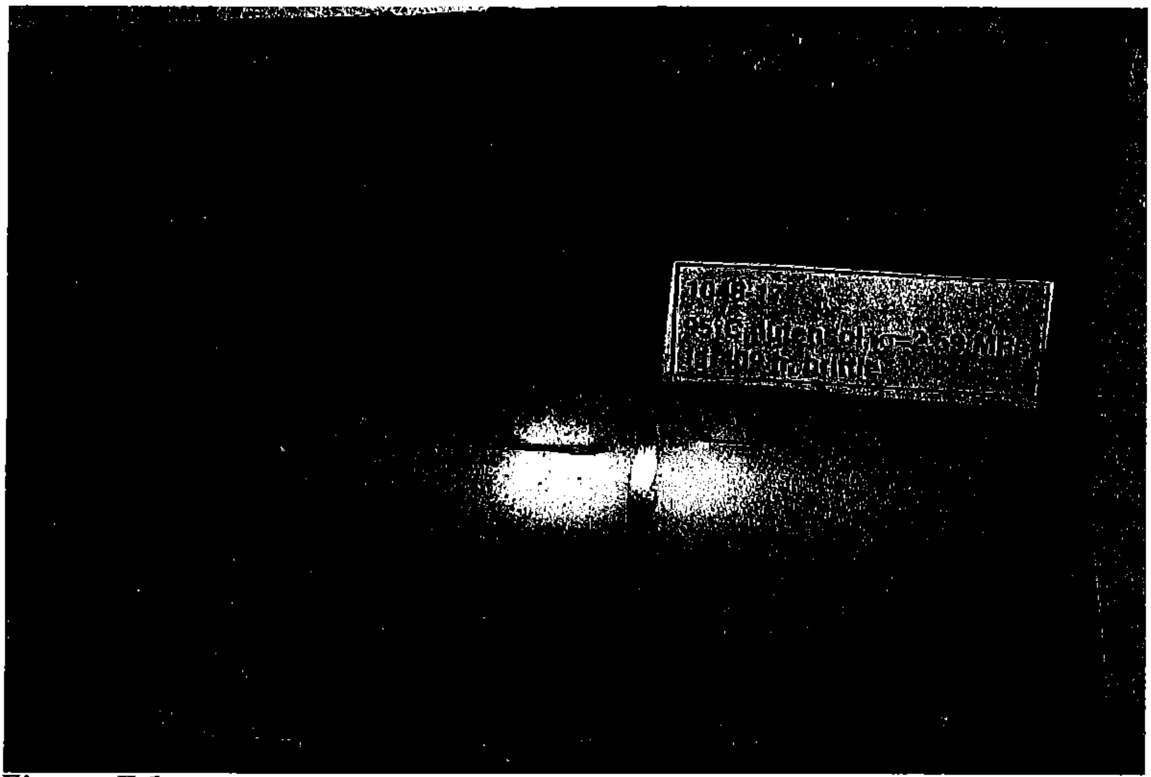

Figure E.1
Detail of the inside of specimen 1048-17, 160 x 14.6 mm MDPE-pipe. The pipe was not subjected to squeeze-off. The pipe was pressure tested at 95°C in Lutensol/water at 2.58 MPa. The failure time was 11 409 h. The primary crack is in the centre of the black circle. A secondary crack can be seen to the right.

Figure E.2
Fracture surface of the specimen in Figure E.1. The inside pipe wall is at the bottom of the picture. Near the inside pipe wall the fracture surface is very brittle. The white regions represents very ductile part of the fracture surface.

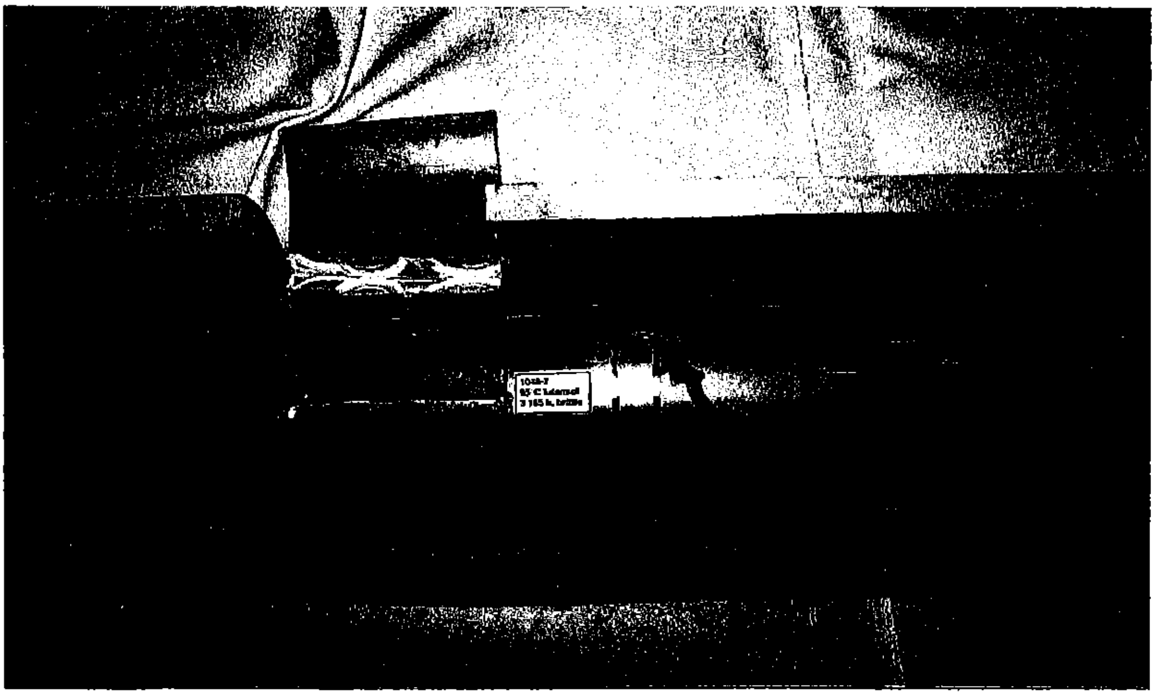

Figure E.3
Detail of the inside of specimen 1048-7, 160 x 14.6 mm MDPE-pipe. The pipe was subjected to normal squeeze-off. The pipe was pressure tested at 95°C in Lutensol/water at 2.61 MPa. The failure time was 3 165 h. The locations of the fracture and the squeeze-off zone are indicated. The fracture zone has bee cut out and cold broken. Many secondary cracks can bee seen at the inside.

Figure E.4
Overview of specimen 1048-6, 160 x 14.6 mm MDPE-pipe. The pipe was subjected to catastrophic squeeze-off. The pipe was pressure tested at 95°C in Lutensol/water at 2.59 MPa. The failure time was 3 425 h. The locations of the fracture and the squeeze-off zone are indicated.

Figure E.5
Fracture surface of the specimen in Figure E.4. The crack was probably initiated by a defect near the outside of the pipe wall. The outer pipe wall is at the top in the figure.

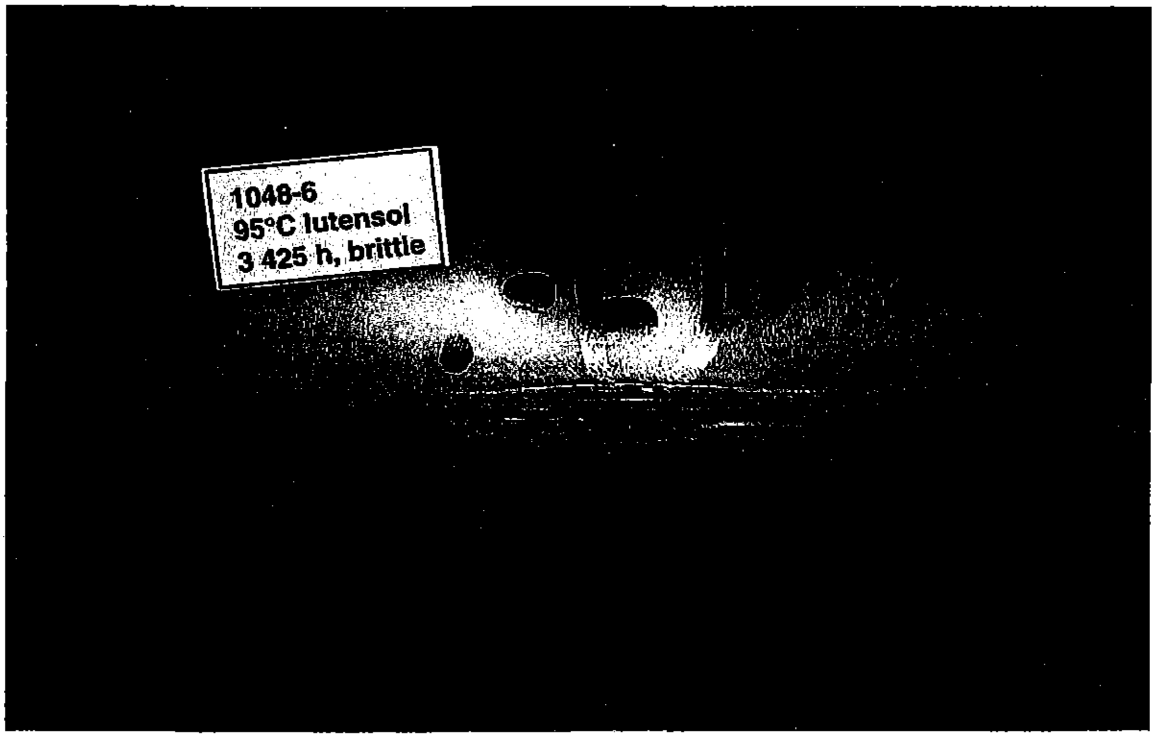

Figure E.6
Detail of the squeeze-off zone for pipe specimen 1048-6 which was subjected to a catastrophic squeeze-off. The markings indicate the location of the bars during squeeze-off operation.

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RAPPORTFÖRTECKNING

SGC Nr	Rapportnamn	Rapport datum	Författare	Pris kr
001	Systemoptimering vad avser ledningstryck	Apr 91	Stefan Grudén TUMAB	100
002	Mikrokraftvärmeverk för växthus. Utvärdering	Apr 91	Roy Ericsson Kjessler & Mannerstråle AB	100
004	Krav på material vid kringfyllnad av PE -gasledningar	Apr 91	Jan Molin VBB VIAK	50
005	Teknikstatus och marknadsläge för gasbaserad minikraftvärme	Apr 91	Per-Arne Persson SGC	150
006	Keramisk fiberbrännare - Utvärdering av en demo-anläggning	Jan 93	R Brodin, P Carlsson Sydkraft Konsult AB	100
007	Gas-IR teknik inom industrin. Användnings- områden, översiktlig marknadsanalys	Aug 91	Thomas Ehrstedt Sydkraft Konsult AB	100
009	Läcksökning av gasledningar. Metoder och instrument	Dec 91	Charlotte Rehn Sydkraft Konsult AB	100
010	Konvertering av aluminiumsmältugnar. Förstudie	Sep 91	Ola Hall, Charlotte Rehn Sydkraft Konsult AB	100
011	Integrerad naturgasanvändning i tvätterier. Konvertering av torktumlare	Sep 91	Ola Hall Sydkraft Konsult AB	100
012	Odöranter och gasolkondensats påverkan på gasrörsystem av polyeten	Okt 91	Stefan Grudén, F. Varmedal TUMAB	100
013	Spektralfördelning och verkningsgrad för gaseldade IR-strålare	Okt 91	Michael Johansson Drifttekniska Inst. vid LTH	150
014	Modern gasteknik i galvaniseringsindustri	Nov 91	John Danelius Vattenfall Energisystem AB	100
015	Naturgasdrivna truckar	Dec 91	Åsa Marbe Sydkraft Konsult AB	100
016	Mätning av energiförbrukning och emissioner före o efter övergång till naturgas	Mar 92	Kjell Wanselius KW Energiprodukter AB	50
017	Analys och förslag till handlingsprogram för området industriell vätskevärmning	Dec 91	Rolf Christensen ÅF-Energikonsult Syd AB	100
018	Skärning med acetylen och naturgas. En jämförelse.	Apr 92	Åsa Marbe Sydkraft Konsult AB	100

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RAPPORTFÖRTECKNING

SGC Nr	Rapportnamn	Rapport datum	Författare	Pris kr
019	Läggning av gasledning med plöjteknik vid Glostorp, Malmö. Uppföljningsprojekt	Maj 92	Fallsvik J, Haglund H m fl SGI och Malmö Energi AB	100
020	Emissionsdestruktion. Analys och förslag till handlingsprogram	Jun 92	Thomas Ehrstedt Sydkraft Konsult AB	150
021	Ny läggningsteknik för PE-ledningar. Förstudie	Jun 92	Ove Ribberström Ove Ribberström Projekt AB	150
022	Katalog över gastekniska FUD-projekt i Sverige. Utgåva 4	Aug 92	Svenskt Gastekniskt Center	150
023	Läggning av gasledning med plöjteknik vid Lillhagen, Göteborg. Uppföljningsproj.	Aug 92	Nils Granstrand m fl Göteborg Energi AB	150
024	Stumsvetsning och elektromuffsvetsning av PE-ledningar. Kostnadsaspekter.	Aug 92	Stefan Grudén TUMAB	150
025	Papperstorkning med gas-IR. Sammanfattning av ett antal FUD-projekt	Sep 92	Per-Arne Persson Svenskt Gastekniskt Center	100
026	Koldioxidgödsling i växthus med hjälp av naturgas. Handbok och tillämpn.exempel	Aug 92	Stig Arne Molén m fl	150
027	Decentraliserad användning av gas för vätskevärmning. Två praktikfall	Okt 92	Rolf Christensen ÅF-Energikonsult	150
028	Stora gasledningar av PE. Teknisk och ekonomisk studie.	Okt 92	Lars-Erik Andersson, Åke Carlsson, Sydkraft Konsult	150
029	Catalogue of Gas Techn Research and Development Projects in Sweden (På engelska)	Sep 92	Swedish Gas Technology Center	150
030	Pulsationspanna. Utvärdering av en demo -anläggning	Nov 92	Per Carlsson, Åsa Marbe Sydkraft Konsult AB	150
031	Detektion av dräneringsrör. Testmätning med magnetisk gradiometri	Nov 92	Carl-Axel Triumf Triumf Geophysics AB	100
032	Systemverkn.grad efter konvertering av vattenburen elvärme t gasvärme i småhus	Jan 93	Jonas Forsman Vattenfall Energisystem AB	150
033	Energiuppföljning av gaseldad panncentral i kvarteret Malörten, Trelleborg	Jan 93	Theodor Blom Sydkraft AB	150
034	Utvärdering av propanexponerade PEM-rör	Maj 93	Hans Leijström Studsvik AB	150

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RAPPORTFÖRTECKNING

SGC Nr	Rapportnamn	Rapport datum	Författare	Pris kr
035	Hemmatankning av naturgasdriven personbil. Demonstrationsprojekt	Jun 93	Tove Ekeborg Vattenfall Energisystem	150
036	Gaseldade genomströmningsberedare för tappvarmvatten i småhus. Litteraturstudie	Jun 93	Jonas Forsman Vattenfall Energisystem	150
037	Verifiering av dimensioneringsmetoder för distributionsledningar. Litt studie.	Jun 93	Thomas Ehrstedt Sydkraft Konsult AB	150
038	NOx-reduktion genom reburning med naturgas. Fullskaleförsök vid SYSAV i Malmö	Aug 93	Jan Bergström Miljökonsulterna	150
039	Pulserande förbränning för torkändamål	Sep 93	Sten Hermodsson Lunds Tekniska Högskola	150
040	Organisationer med koppling till gasteknisk utvecklingsverksamhet	Feb 94	Jörgen Thunell SGC	150
041	Fältsortering av fyllnadsmassor vid läggning av PE-rör med läggningsbox.	Nov 93	Göran Lustig Elektro Sandberg Kraft AB	150
042	Deponigasens påverkan på polyetenrör.	Nov 93	Thomas Ehrstedt Sydkraft Konsult AB	150
043	Gasanvändning inom plastindustrin, handlingsplan	Nov 93	Thomas Ehrstedt Sydkraft Konsult AB	150
044	PA 11 som material ledningar för gasdistribution.	Dec 93	Thomas Ehrstedt Sydkraft Konsult AB	150
045	Metoder att höja verkningsgraden vid avgaskondensering	Dec 93	Kjell Wanselius KW Energiprodukter AB	150
046	Gasanvändning i målerier	Dec 93	Charlotte Rehn et al Sydkraft Konsult AB	150
047	Rekuperativ aluminiumsmältugn. Utvärdering av degelugn på Värnamo Pressgjuteri.	Okt 93	Ola Hall Sydkraft Konsult AB	150
048	Konvertering av dieseldrivna reservkraftverk till gasdrift och kraftvärmeprod	Jan 94	Gunnar Sandström Sydkraft Konsult AB	150
049	Utvecklad teknik för gasinstallationer i småhus	Feb 94	P Kastensson, S Ivarsson Sydgas AB	150
050	Korrosion i flexibla rostfria insatsrör (Finns även i engelsk upplaga)	Dec 93	Ulf Nilsson m fl LTH	150

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RAPPORTFÖRTECKNING

SGC Nr	Rapportnamn	Rapport datum	Författare	Pris kr
051	Nordiska Degelugnsprojektet. Pilot- och fältförsök med gasanvändning.	Nov 93	Eva-Maria Svensson Glafo	150
052	Nordic Gas Technology R&D Workshop. April 20, 1994. Proceedings.(På engelska)	Jun 94	Jörgen Thunell, Editor Swedish Gas Center	150
053	Tryckhöjande utrustning för gas vid metallbearbetning -- En förstudie av GT -PAK	Apr 94	Mårten Wärnö MGT Teknik AB	150
054	NOx-reduktion genom injicering av naturgas i kombination med ureainsprutning	Sep 94	Bent Karll, DGC P Å Gustafsson, Miljökons.	100
055	Trevägskatalysatorer för stationära gasmotorer.	Okt 94	Torbjörn Karlelid m fl Sydkraft Konsult AB	150
056	Utvärdering av en industriell gaseldad IR -strålare	Nov 94	Johansson, M m fl Lunds Tekniska Högskola	150
057	Läckagedetekteringssystem i storskaliga gasinstallationer	Dec 94	Fredrik A Silversand Katator AB	150
058	Demonstration av låg-NOx-brännare i växthus	Feb 95	B Karll, B T Nielsen Dansk Gasteknisk Center	150
059	Marknadspotential naturgaseldade industriella IR-strålare	Apr 95	Rolf Christensen Enerkon RC	150
060	Rekommendationer vid val av flexibla insatsrör av rostfritt i villaskorstenar	Maj 95	L Hedeen, G Björklund Sydgas AB	50
061	Polyamidrör för distribution av gasol i gasfas. Kunskapssammanställning	Jul 95	Tomas Tränkner Studsvik Material AB	150
062	PE-rörs tålighet mot yttre påverkan. Sammanställning av utförda praktiska försök	Aug 95	Tomas Tränkner Studsvik Material AB	150
063	Naturgas på hjul. Förutsättningar för en storskalig satsning på NGV i Sverige	Aug 95	Naturgasbolagens NGV- grupp	150
064	Energieffektivisering av större gaseldade pannanläggningar. Handbok	Aug 95	Lars Frederiksen Dansk Gasteknisk Center	200
065	Förbättra miljön med gasdrivna fordon	Aug 95	Göteborg Energi AB	150
066	Konvertering av oljeeldade panncentraler till naturgas. Handbok.	Nov 95	Bo Cederholm Sydkraft Konsult AB	150

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RAPPORTFÖRTECKNING

SGC Nr	Rapportnamn	Rapport datum	Författare	Pris kr
067	Naturgasmodellen. Manual för SMHI:s program för beräkn av skorstenshöjder	Dec 95	Tingnert B, SKKB Thunell J, SGC	150
068	Energigas och oxyfuelteknik	Dec 95	Ingemar Gunnarsson Energi-Analys AB	150
069	CO2-gödsling med avgaser från gasmotor med katalysator	Dec 95	Bent Karll Dansk Gasteknisk Center	150
070	Utvärdering av naturgasförbränning i porösa bäddar	Mar 96	Henric Larsson Lunds Tekniska Högskola	150
071	Utvärdering av naturgasdrivna IR-boostrar i ugn för pulverlackering	Nov 95	Ole H Madsen Asger N Myken	150
072	Sammanställning av emissionsdata från naturgas-, biogas- o motorgasdrivna fordon	Jun 96	Hans-Åke Maltesson Svenskt Gastekniskt Center AB	150
073	Livslängdsbestämning för PE-rör för gasdistribution (EVOPE-projektet)	Jul 96	Tomas Tränkner Studsvik Material AB	100
074	Gasblandningar för fordonsdrift. Idéstudie.	Aug 96	Ola Hall Sydkraft Konsult AB	150
075	Gasbranschens miljöhandbok	Sep 96	Jörgen Thunell Svenskt Gastekniskt Center	500
076	Låg-NOx-teknik för gasdrivna processer - dagsläge	Okt 96	Mikael Näslund, LTH Inst.Värme- och Kraftteknik, LTH	150
077	Karakterisering av emissioner från naturgasdrivna lastbilar inom LB 50 -projektet	Dec 96	K-E Egebäck Roger Westerholm	150
078	Uppvärmning med gas i svenska småhus - erfarenheter och framtida teknikval	Nov 96	Mikael Näslund, LTH	150
079	Handledn. för inst av gaseldade IR -värmare. Rådgivning, analys och genomförande	Apr 97	Pär Dalin DITAB	150
080	Mikrokraftvärmeverk med Stirlingmotor	Jan 97	Tomas Nilsson Lunds Tekniska Högskola	150
081	Naturgasbaserad småskalig kraftvärme inom uppvärmningssektorn	Feb 97	Mats Nilsson LTH/MALMÖ	150
082	Kylning och klimatisering av byggnader och lokaler med hjälp av naturgas	Apr 97	Anders Lindkvist Vattenfall Energisystem	150

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RAPPORTFÖRTECKNING

SGC Nr	Rapportnamn	Rapport datum	Författare	Pris kr
083	Naturgassystemet i Sverige - en teknisk beskrivning	Jun 97	Ronny Nilsson, KM	150
084	Livscykelanalyser - Är det något för gasbranschen	Sep 97	Jörgen Thunell	150
085	Konvertering av direktelvärmda småhus till naturgasuppvärmning	Dec 97	Mikael Näslund Inst Värme- och Kraftteknik, LTH	150
086	Uppgradering av biogas . Fas 2, Praktiska försök med kondenseringsmetoder.	Jun 97	Ola Lloyd / BioMil AB Johan Nilsson / LTH	150
087	Utveckling av katatalytisk rening av avgaser från befintlig panna	Dec 97	F Silversand, T Hargitai m fl Katator AB	150
088	Technical Description of the Swedish Natural Gas Distr System (På Engelska)	Jun 97	Ronny Nilsson, KM	150
089	Rening av avgaser från en naturgasdriven lean burn motor i en förbr.växlare	Okt 97	Björn Heed Inst för Energiteknik, CTH	150
090	Utsläpp av oreglerade ämnen vid förbränning av olika bränslen	Jun 98	Jörgen Thunell	150
091	Nya metoder för att säkerställa mätnoggrannheten i naturgasnät	Nov 97	Ulf R C Nilsson Luleå TH, Inst Systemteknik	150
093	Karaktärisering av emissioner från naturgasdrivna lastbilar inom LB50 -projektet	Sep 98	Karl Erik Egebäck	150
095	Karaktärisering av emissioner från naturgasdrivna lastbilar inom LB50 -projektet	Okt 98	Karl Erik Egebäck	150
096	Lifetime of PE-pipes subjected to squeeze off	Nov 98	Tomas Tränkner	150
A01	Fordonstankstation Naturgas. Parallellkoppling av 4 st Fuel Makers	Feb 95	Per Carlsson Göteborg Energi AB	50
A02	Uppföljning av gaseldade luftvärmare vid Arlövs Sockerraffinaderi	Jul 95	Rolf Christensen Enercon RC	50
A03	Gasanvändning för färjedrift. Förstudie (Endast för internt bruk)	Jul 95	Gunnar Sandström Sydkraft Konsult	0
A04	Bussbuller. Förslag till mätprogram	Jun 95	Ingemar Carlsson Ecotrans Teknik AB	50

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RAPPORTFÖRTECKNING

SGC Nr	Rapportnamn	Rapport datum	Författare	Pris kr
A05	Värmning av vätskor med naturgas - Bakgrund till faktablad	Okt 95	Rolf Christensen Enerkon RC	50
A06	Isbildning i naturgasbussar och CNG -system (Endast för internt bruk)	Nov 95	Volvo Aero Turbines Sydgas, SGC	0
A07	Större keramisk fiberbrännare. Förstudie	Jan 96	Per Carlsson Sydkraft Konsult AB	50
A08	Reduktion av dioxin, furan- och klorfenoler vid avfallsförbränning	Maj 96	H Palmén, M Lampinen et al Helsingfors Tekniska Högskola	50
A09	Naturgas/mikrovågsteknik för sintring av keramer	Maj 96	Anders Röstin KTH	50
A10	NOx-reduktion genom naturgasinjektion o reburning. Demoprojekt på Knudmoseverket	Apr 96	Jan Flensted Poulsen Völund R & D Center	50
A11	Direkttorkning av socker med naturgas (Endast för internt bruk)	Jul 96	Rolf Christensen Enerkon RC	0
A12	Uppföljning, installation av gaspanna med avgaskondensor, kv Hornblåsaren 6, Råå	Sep 96	Bo Cederholm Sydkraft Konsult AB	50
A13	Klassningsplaner för gasinstallationer	Jun 97	Carl-Axel Stenberg Greger Arnesson	50
A14	Uppf av drift med natugaseldad kondenserande gaspanna i Rinnebäcksskolan	Okt 97	Bo Cederholm Sydkraft Konsult AB	50
A15	Undersökn o förstärkn av korr.skyddet på gasrör förl i skyddsrör - Delrapport 1	Nov 97	Åsa Marbe, C Johansson Sydkraft Konsult AB	100
A16	Ind - CO2-härdning av betong med naturgas	Feb 98	Åsa Marbe Sydkraft Konsult AB	50
A17	Reservförsörjning med fordonstransporterad LNG	Dec 97	Stig Johansen	50
A18	Emissions- och immissionsmätning vid en naturgaseldad villapanna	Mar 97	David Cooper IVL	50
A19	Katalytisk rening av gaseldade lean -burnmotorer etapp 1 - teoretisk förstudie		Fredrik Silversand Katatro	100
				0

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