RESULTS AND EXPERIENCES FROM TESTS ON PEX, PEM, PP AND PVC PIPES EXPOSED TO DIFFERENT CHEMICALS

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This paper presents experimental data for PEX, PEM, PP and PVC pipes exposed to different chemicals. More than 150 plastic pipes of PEX, PEM, PP and PVC have been pressure tested with different chemicals. The chemicals used are; 97% Sulfuric acid, 100% Acetic acid, 30% Sodium hydroxide and a solution of 50% Trimethylbensene and 50% n-Decan. The results are compared with hydrostatic pressure tests in water. Extrapolation using Arrhenius are discussed and demonstrated. Discussions about the failure mechanisms are presented illustrated by fractography.

Based on the results a description of a new testing procedure to investigate the chemical resistance for plastic pipes is also presented.

INTRODUCTION

The lifetime of plastic pipes used for distribution of hot-water, gas and industrial chemicals has been investigated at Studsvik since 1973 [1-3].

Between 1987 and 1991 Studsvik performed a project together with the plastic pipe industry to study the influence of different chemicals on the long-term performance of plastic pipes.

During these four years 150 plastic pipes have been investigated. The project included pipes of Cross-linked Polyethylene (PEX), Medium density Polyethylene (PEM), Polypropylene (PP) and Polyvinylchlorine (PVC). Earlier studies of plastic pipes exposed for different chemicals have mainly been performed by Dr. E. Gaube, Dr. W. Müller and Ing. G. Diedrich at Hoechst, Germany [4-5].

INVESTIGATED MATERIALS

The results presented in this report are based on four commercial pipe materials. The pipe materials are; Cross-linked Polyethylene (PEX), Medium density Polyethylene (PEM), Polypropylene (PP) and Polyvinylchlorine (PVC). The nominal dimension for PEX, PEM and PP is 32 x 3 mm (outer diameter x thickness). For PVC the nominal dimension is 32 x 1.6 mm (outer diameter x thickness).

EXPERIMENTAL PROCEDURES

All tests have been performed at the Polymer laboratory at Studsvik Polymer AB. The hydrostatic pressure testing equipment has been designed and built by Studsvik.

RESULTS

In general a creep rupture curve can be divided in three different parts, Stage I, II and III [1].
At high hoop stresses (Stage I), ductile failures are obtained when large defects are absent in the material. At lower stresses (Stages II and III), there is a competition between mechanical phenomena (slow crack growth) and chemical degradation (thermal oxidation) which gives brittle failures in a macroscopic sense. For Stage III, the curve is almost vertical which clearly demonstrates the extreme brittleness of the material. At Stage III the very lifetime has been reached for a pipe material.

Testing of PEX, PEM, PP and PVC pipes exposed to 97% Sulfuric acid
Sulfuric acid is a very strong oxidizer. When plastic pipes are exposed for Sulfuric acid the inside of the pipe will be totally degraded with a lot of radial cracks which decrease the lifetime. The plastic pipe will fail by weeping or brittle failure.

The results for PEX, PEM, PP and PVC pipes exposed to 97% Sulfuric acid are presented in Figures 1, 3, 5 and 7. By using the Arrhenius relationship we can at a given hoop stress predict a preliminary lifetime at different temperatures. The Arrhenius relationship are presented in Figures 2, 4, 6 and 8.

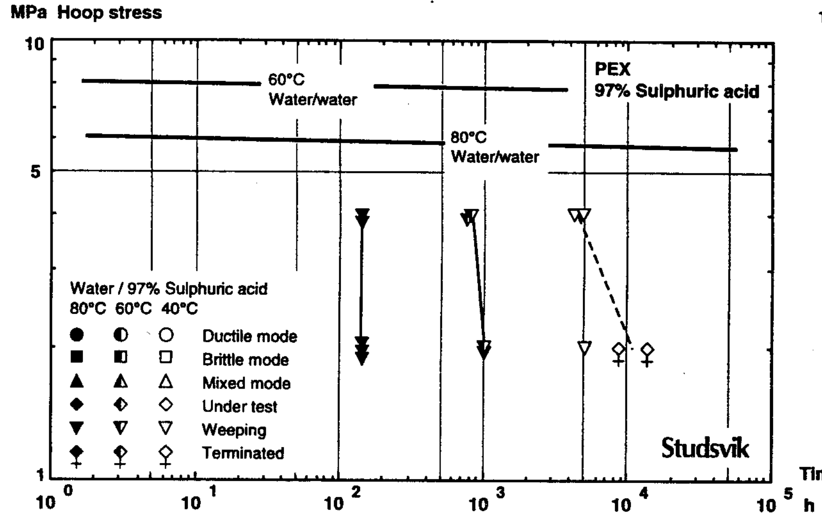


Figure 1

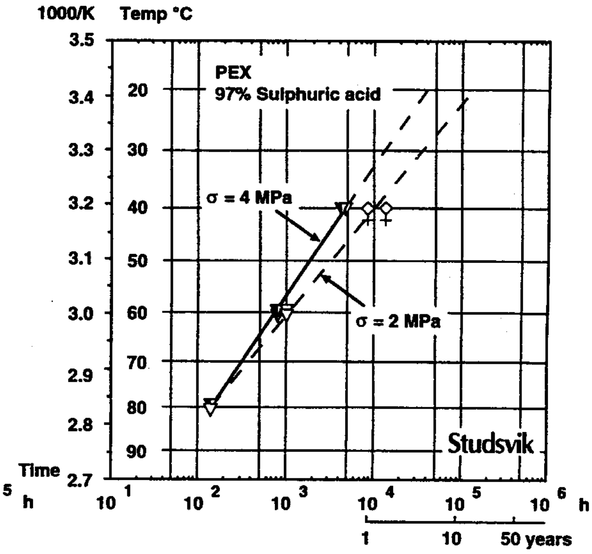


Figure 2

Figure 1 presents the results from the hydrostatic pressure testing of PEX at 40, 60 and 80°C using 97% Sulfuric acid as the internal medium and water as the external medium. For comparison the lines for testing at 60 and 80°C water/water are included. Figure 2 shows the Arrhenius relationship for PEX in 97% Sulfuric acid at 2 and 4 MPa at different temperature.

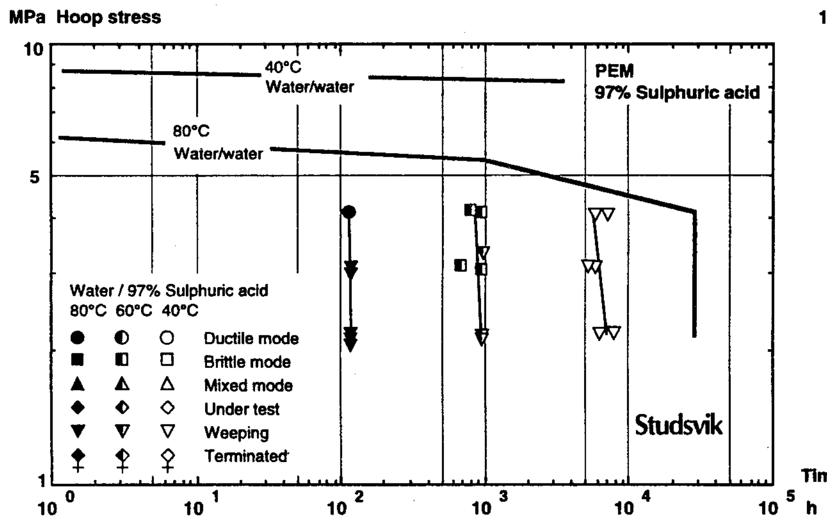


Figure 3

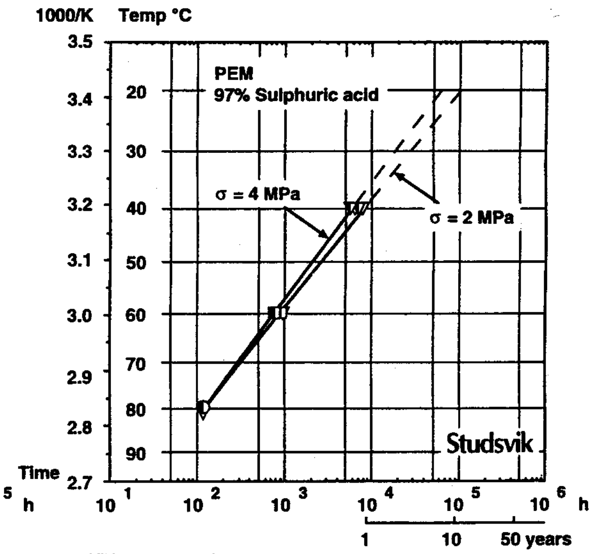
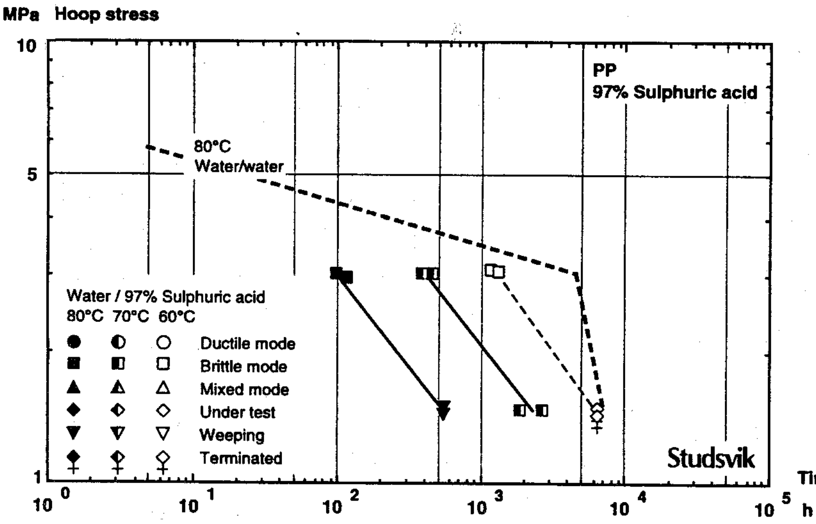


Figure 4

Figure 3 presents the results from the hydrostatic pressure testing of PEM at 40, 60 and 80°C using 97% Sulfuric acid as the internal medium and water as the external medium. For comparison the lines for testing at 40 and 80°C water/water are included. Figure 4 shows the Arrhenius relationship for PEM in 97% Sulfuric acid at 2 and 4 MPa at different temperature.



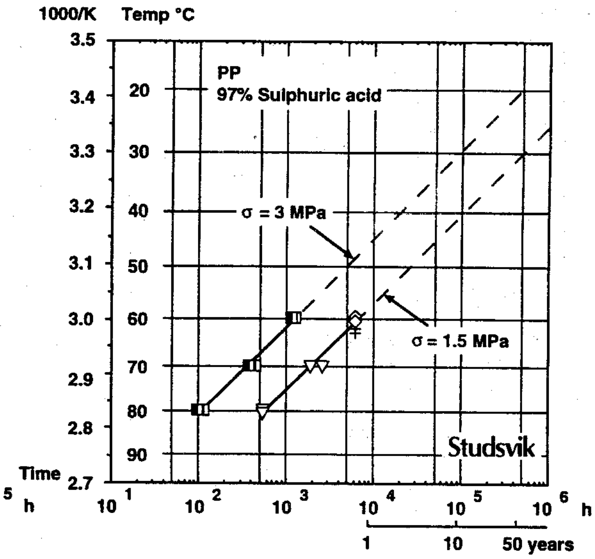
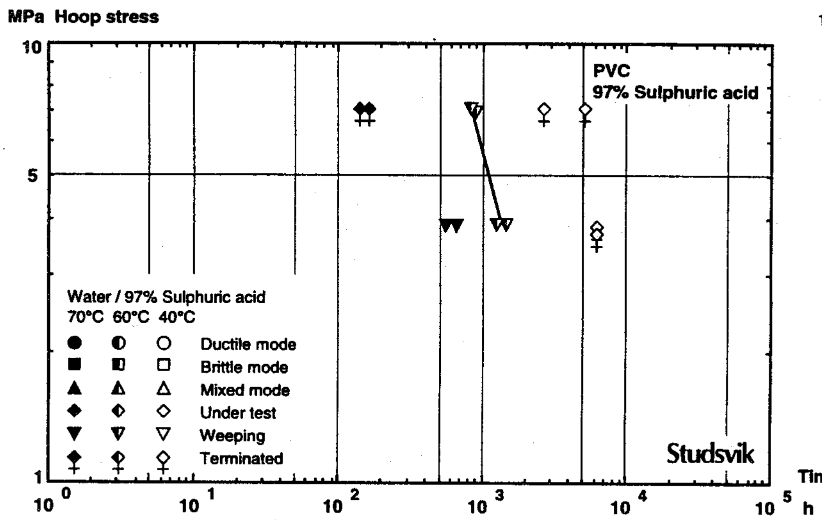


Figure 5 **Figure 6**

Figure 5 presents the results from the hydrostatic pressure testing of PP at 60, 70 and 80°C using 97% Sulfuric acid as the internal medium and water as the external medium. For comparison the line for testing at 80°C water/water is included. Figure 6 shows the Arrhenius relationship for PP in 97% Sulfuric acid at 1.5 and 3 MPa at different temperature.



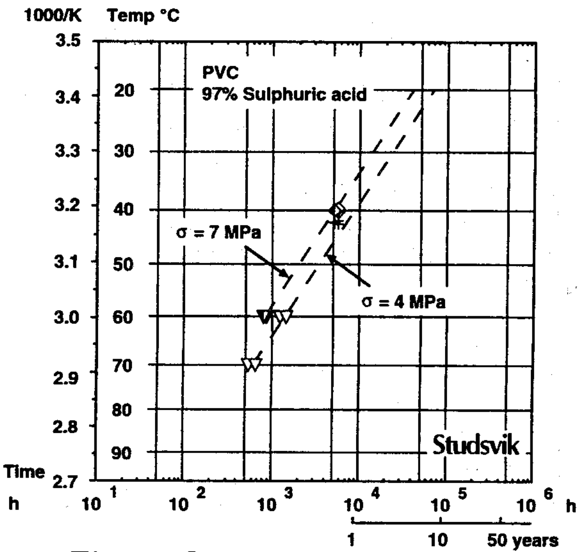
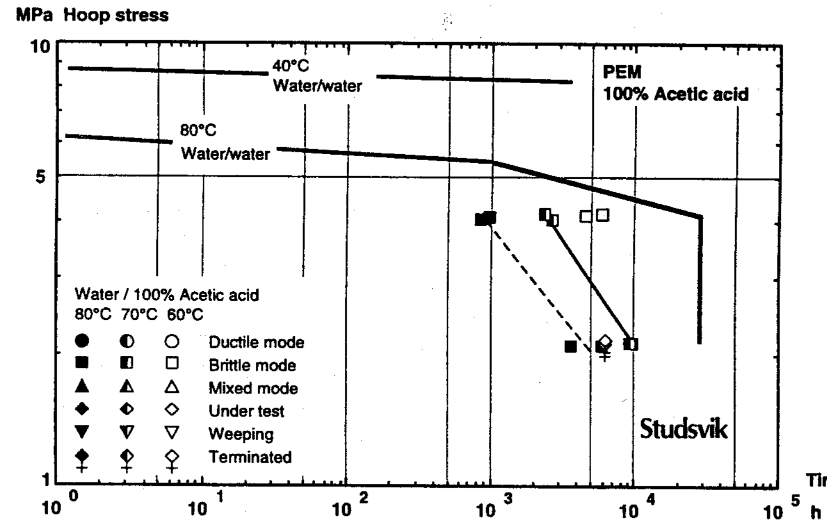


Figure 7 **Figure 8**

Figure 7 presents the results from the hydrostatic pressure testing of PVC at 40, 60 and 70°C using 97% Sulfuric acid as the internal medium and water as the external medium. Figure 8 shows the Arrhenius relationship for PVC in 97% Sulfuric acid at 4 and 7 MPa at different temperature.

Testing of PEX and PEM pipes exposed to 100% Acetic acid

Acetic acid acts as an Environmental Stress Cracking Agent (ESCA). The results show that 100% Acetic acid are not so aggressive for PEX pipes. After an exposure time of 5 700 h at 80°C the tests were terminated. The results for PEM pipes exposed to 100% Acetic acid are presented in Figure 9. The results show a clear Stage II and the brittle failures are true Stage II failures caused by stress cracking. By using the Arrhenius relationship we can at a given hoop stress predict a preliminary lifetime at different temperatures. The Arrhenius relationship for PEM is presented in Figure 10.



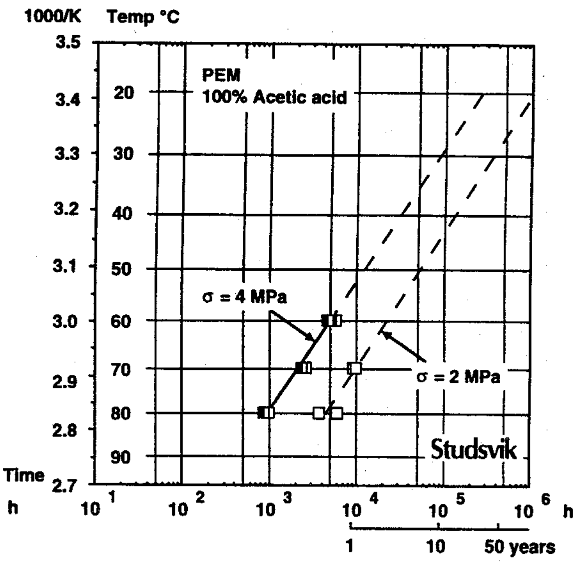


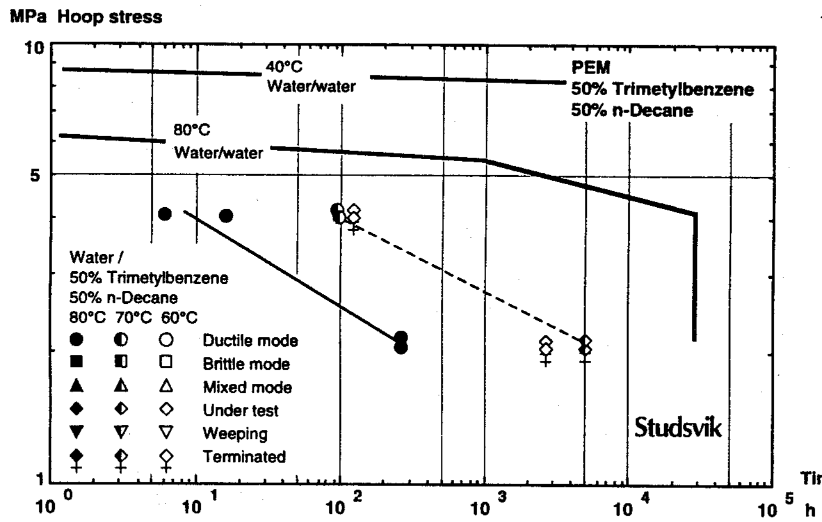
Figure 9 **Figure 10**

Figure 9 presents the results from the hydrostatic pressure testing of PEM at 60, 70 and 80°C using 100% Acetic acid as the internal medium and water as the external medium. For comparison the lines for testing at 40 and 80°C water/water are included. Figure 10 shows the Arrhenius relationship for PEM in 100% Acetic acid at 2 and 4 MPa at different temperature.

Testing of PEX and PEM pipes exposed to 50/50 Trimethylbensene and n-Decan

The mixture of 50% Trimethylbensene and 50% n-Decan have a very strong softening effect on plastic pipes which leads to an increase of the circumferential elongation for the pressurized plastic pipes.

The results for the PEM pipes exposed to 50/50 Trimethylbensene and n-Decan are presented in Figure 11. By using the Arrhenius relationship we can at a given hoop stress predict a preliminary lifetime for the PEM material at different temperatures. The Arrhenius relationship is presented in Figure 12.



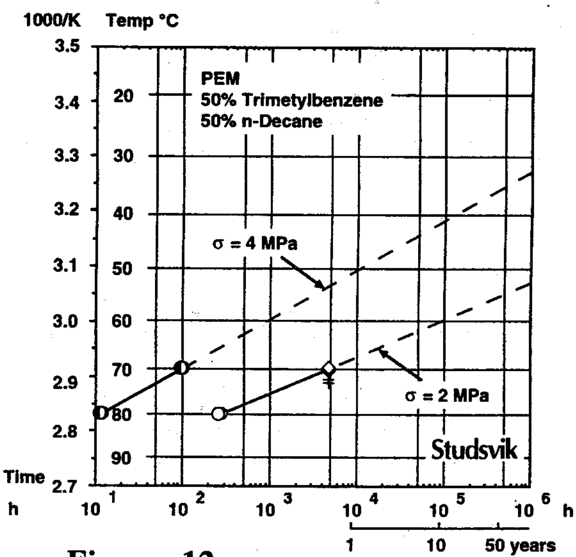


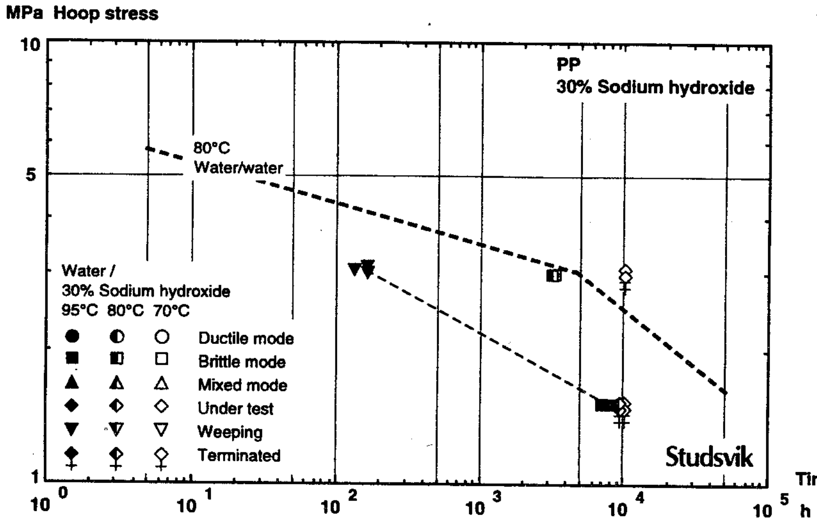
Figure 11 **Figure 12**

Figure 11 presents the results from the hydrostatic pressure testing of PEM at 60, 70 and 80°C using 50% Trimethylbensene and 50% n-Decan as the internal medium and water as the external medium. For comparison the lines for testing at 40 and 80°C water/water are included. Figure 12 shows the Arrhenius relationship for PEM in 50% Trimethylbensene and 50% n-Decan at 2 and 4 MPa at different temperature.

Testing of PP and PVC pipes exposed to 30% Sodium hydroxide

The chemical effect for PP and PVC pipes exposed to a solution of 30% Sodium hydroxide is quite small. This has also been shown in earlier studies [4-5].

The results for PP and PVC pipes exposed to 30% Sodium hydroxide are presented in Figures 13 and 15. By using the Arrhenius relationship we can at a given hoop stress predict a preliminary lifetime at different temperatures. The Arrhenius relationship are presented in Figures 14 and 16.



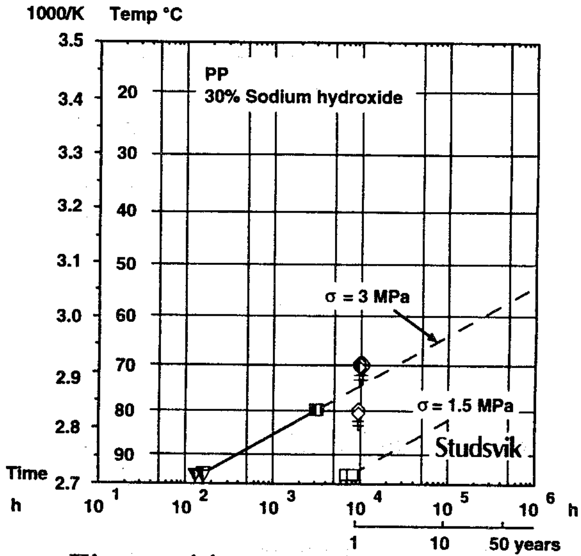
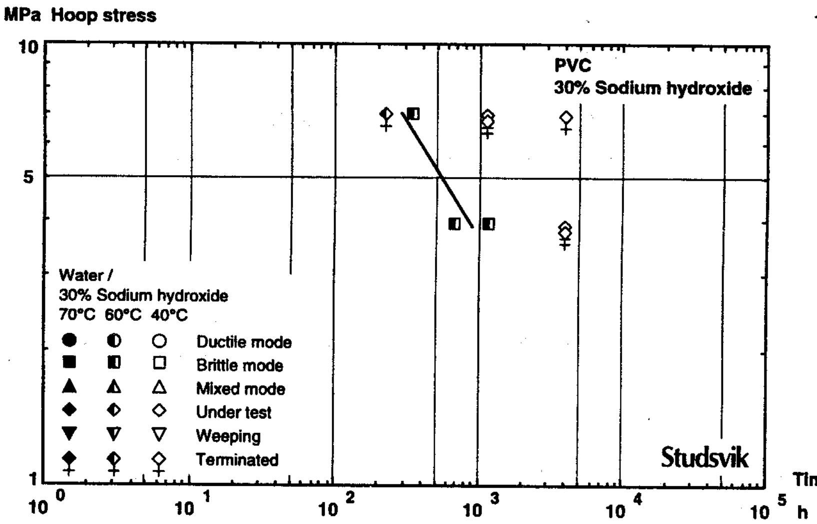


Figure 13 **Figure 14**

Figure 13 presents the results from the hydrostatic pressure testing of PP at 70, 80 and 95°C using 30% Sodium hydroxide as the internal medium and water as the external medium. For comparison the line for testing at 80°C water/water is included. Figure 14 shows the Arrhenius relationship for PP in 30% Sodium hydroxide at 1.5 and 3 MPa at different temperature.



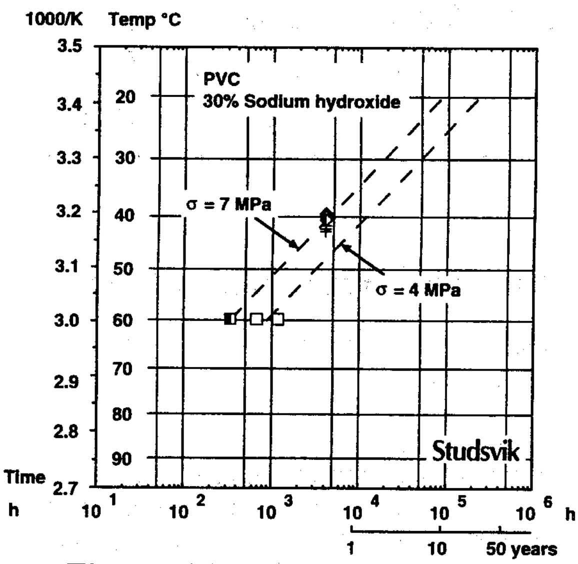


Figure 15 **Figure 16**

Figure 15 presents the results from the hydrostatic pressure testing of PVC at 40, 60 and 70°C using 30% Sodium hydroxide as the internal medium and water as the external medium. Figure 16 shows the Arrhenius relationship for PVC in 30% Sodium hydroxide at 4 and 7 MPa at different temperature.

Table I present the estimated temperature at a given hoop stress that gives a lifetime of 10 years for the different investigated materials.

Table I. Predicted 10 years lifetimes for plastic pipes exposed to different chemicals

Environment	*Material*	*Hoop stress MPa*	*Temperature °C*
97% Sulfuric acid	*PEX*	*4*	*12*
	PEX	*2*	*24*
	PEM	*4*	*19*
	PEM	*2*	*20*
	PP	*3*	*31*
	PP	*1.5*	*42*
	PVC	*4*	*19*
100% Acetic acid	*PEX*	*4*	*50*
	PEM	*4*	*33*
50/50 Trimethylbensene and n-Decan	*PEX*	*4*	*>42*
	PEX	*2*	*>60*
	PEM	*4*	*42*
	PEM	*2*	*60*
30% Sodium hydroxide	*PP*	*3*	*63*
	PP	*1.5*	*80*
	PVC	*4*	*>28*

RESULTS AND DISCUSSION

During the investigation with plastic pipes exposed to different chemicals some problems have been identified.

Weeping failures

When plastic pipes are exposed to some chemicals weeping failures may occur. Weeping failure is when the pipe is "bleeding". In Figure 17 a photo of a PEM pipe can be seen which was exposed to 97% Sulfuric acid and the pipe shows clear weeping. The cross section with a lot of radial cracks can be seen in Figure 18. The inside of the pipe is totally degraded. It is quite difficult to establish the failure time with weeping failure. If the conventional registration technique of the failure time should be used, the leakage of the chemical has to be so large that the pressure decreases. At this time the lifetime of the pipe has already been exceeded. By analyzing the water in the holder it is easier to establish when weeping occur. In Figure 19 the results from the titration of the water in the holder with 0.1 N Sodium hydroxide is presented. The definition of a weeping failure has in this investigation been defined as when an accelerated increase of chemicals in the holder has been observed. The problem with weeping failure and a suggestion to identify when weeping failures occur is described in the ISO document 8584-1[6]. However, is should be an advantage if the ISO document [6] had a more detail definition how to define the weeping failures.

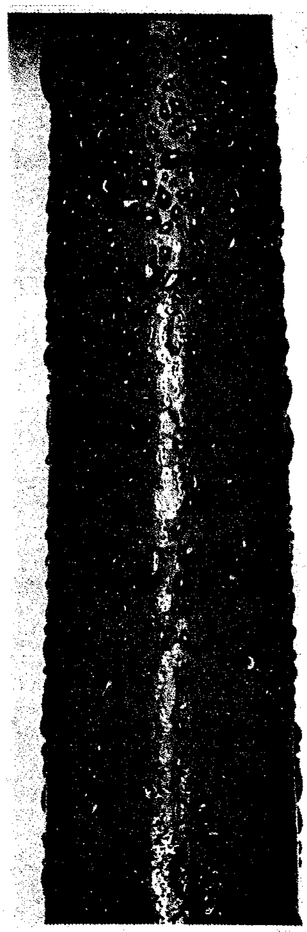


Figure 17
The outside of the PEM pipe which was pressure tested with 97% Sulfuric acid at 60°C and 3.30 MPa during 1 296 h. The pipe shows clear weeping.

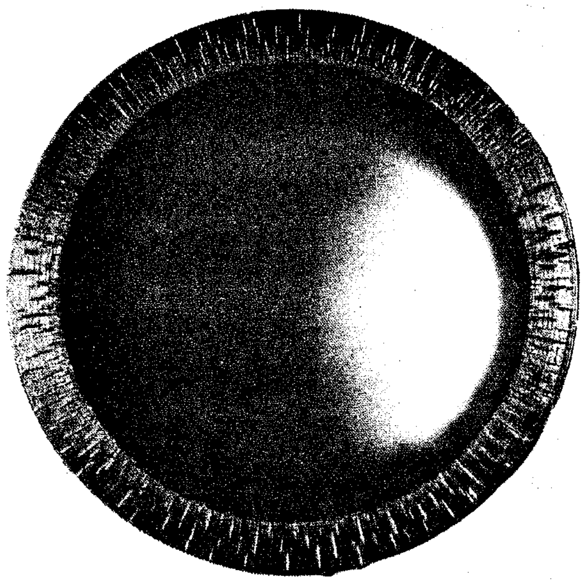


Figure 18
The cross section for the PEM pipe. The cross section is covered with radial cracks.

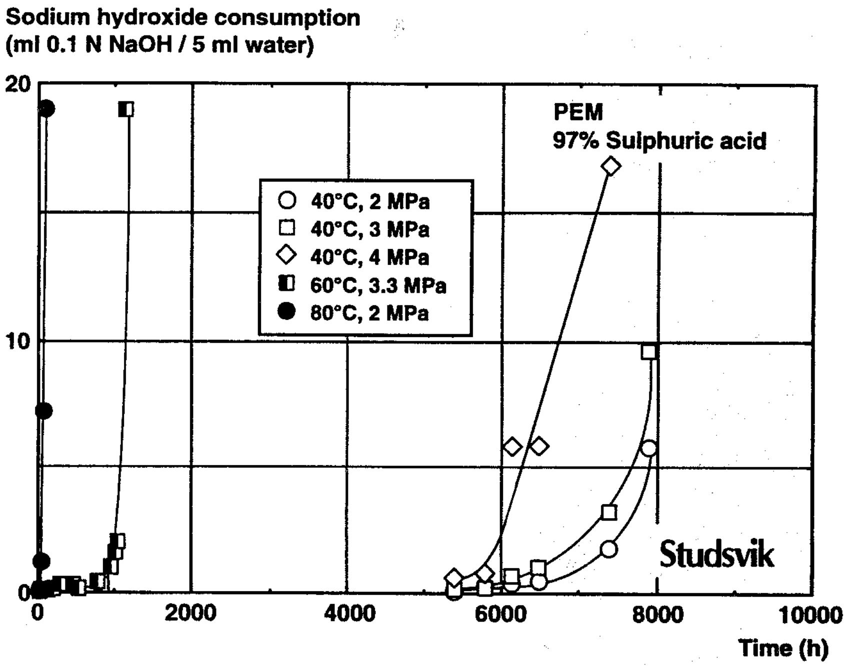


Figure 19

The results from the titration of the water in the holder during the pressure test of the PEM material exposed to 97% Sulfuric acid. The titration was performed by using 0.1 N Sodium hydroxide.

Diffusion and diluting

The investigation also shows that it is very important to have knowledge of the different chemicals diffusion. In Figure 20 the diluting of the Acetic acid on the inside of the pipe as a function of time is presented. This results show that if testing is carried out on longer time than 1 000 h the chemical inside the pipe will be diluted by diffusion of chemical out of the pipe and by water getting into the pipe.

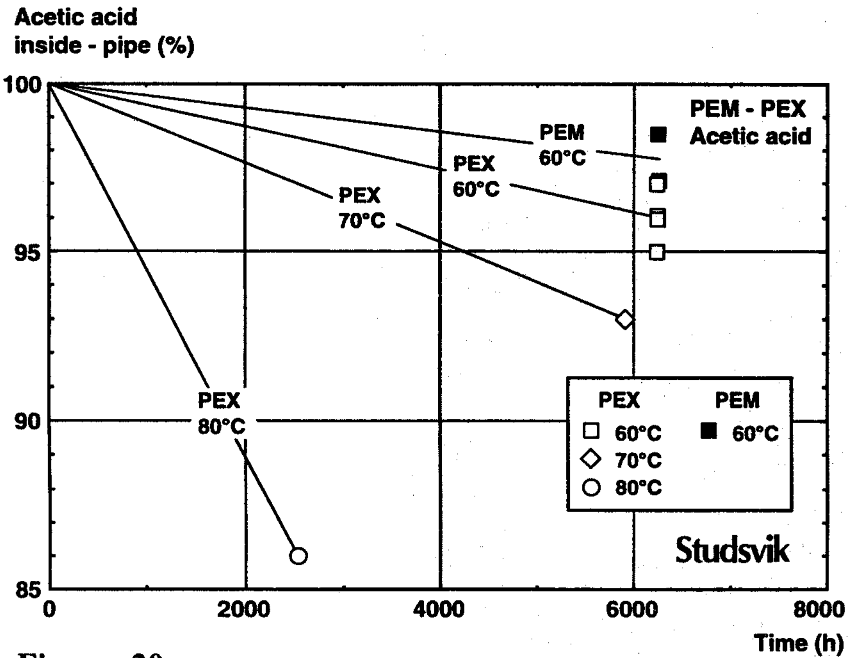


Figure 20

The results from the diluting of the 100% Acetic acid on the inside of the PEM and PEX pipes as a function of time.

Chemicals which have a softening effect on plastic pipes

When pipes are exposed to 50/50 Trimethylbensene and n-Decan the increase of the circumferential elongation of the pipe is very large and the pipe fails with a burst. In Figure 21 the circumferential elongation for a PEM pipe as a function of time is shown. When the increase of the circumferential elongation of the pipe is large it is very important to have a reservoir of the chemical. In Figure 22 the remaining volume 50/50 Trimethylbensene and n-Decan as a function of time is presented. Due to safety reasons, pipes which are exposed to chemicals which have a softening effect of the plastic pipes, the failure criteria should not be based on real failures instead the failure should be based on the increase of the circumferential elongation reaching a certain level.

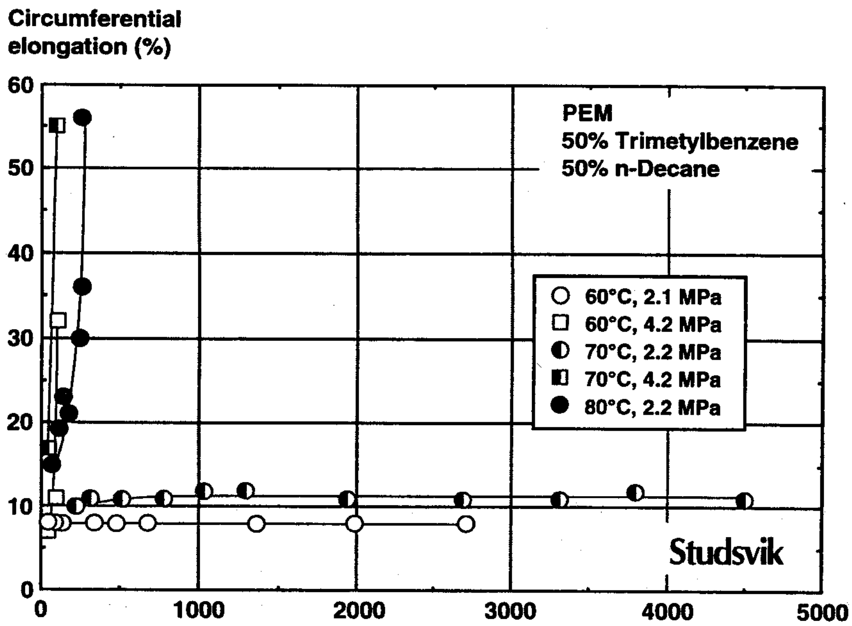


Figure 21

The results for the increase of the circumferential elongation for the PEM pipe as a function of time.

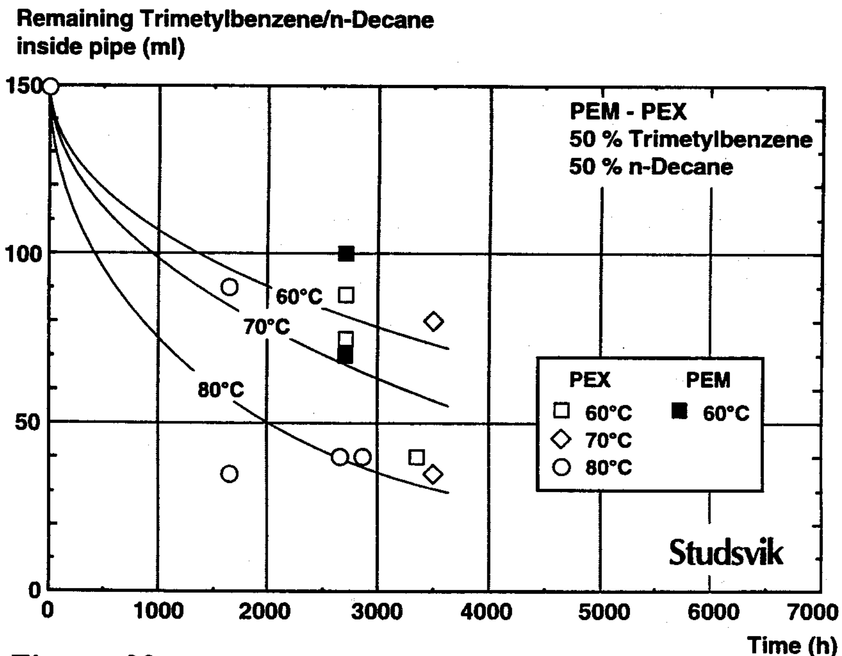


Figure 22

The results of the remaining volume 50/50 Trimethylbensene and n-Decan on the inside of the PEM and PEX pipes which have been hydrostatically pressure tested at 60, 70 and 80°C. The volume was from the beginning 150 ml.

New testing procedure

The most common way to describe the chemical resistance for plastic pipe is by using the chemical resistance factors [4-5]. This is defined as the ratio between the failure time in a specific chemical and the failure time in water at a specific hoop stress and temperature. The problem using the chemical resistance factors to define the chemical resistance is that the materials today have very long lifetimes in water. To establish the lifetime in water will take a very long time and be very costly.

In order to solve the problem with the chemical resistance factors and the other described problems a new testing procedure is suggested. The plastic pipes exposed to different chemicals should be based on the Arrhenius relationship without comparing the results with water. The exposure time should not be longer than 1 000 h due to the diffusion and diluting of the chemicals. The test should be carried out with smaller pipe size (12 x 2 mm) in order to reduce cost and to increase the safety during the experiment. A maximum of six pipes should be pressure tested at two different hoop stresses and at three different temperatures. In order to get failures within 1 000 h the test will be accelerated by increasing the temperature. After a certain time the temperature, for the pipes at the lowest temperature, will be increased in order to get failures within 1 000 h. This described test procedure is only valid for chemicals which are stable. If unstable chemicals are used, such as chlorine, a circulation loop is needed [7]. This test will of course be more costly. If the environment is even more complicated and the chemical is a mixture of different chemicals then the test has to be carried out in the field using a mobile test equipment. This test will be even more costly.

CONCLUSIONS

- The problem using the chemical resistance factors to define the chemical resistance is that the materials today have very long lifetimes in water. To establish the lifetime in water/water will take a very long time and be very costly. A new testing procedure is suggested for plastic pipes exposed to different chemicals which is based on the Arrhenius relationship without comparing the results with water.

- The new testing procedure should be based on smaller pipe size (12 x 2 mm) and the exposure time should not be longer than 1 000 h in order to lower the cost and to increase the safety during the experiment.

- It is very important to have knowledge of the different chemicals diffusion. The investigation shows that if testing is carried out longer time than 1 000 h the chemical inside the pipe has been diluted by diffusion of chemical out of the pipe and by water getting into the pipe.

- Due to safety reasons, the failure criteria should not be based on real failures when pipes are exposed to chemicals which have a softening effect on the plastic pipes. Instead the failure should be based on the increase of the circumferential elongation reaching a certain level.

- The new test procedure is only valid for chemicals which are stabile. For unstable chemicals or a complex mixture of chemicals more advanced experiments have to be performed.

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