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SERIES L: CONSTRUCTION, INSTALLATION AND
PROTECTION OF CABLES AND OTHER ELEMENTS
OF OUTSIDE PLANT

**Method for estimating the concentration of
hydrogen in optical fibre cables**

ITU-T Recommendation L.27

(Previously CCITT Recommendation)

ITU-T L-SERIES RECOMMENDATIONS
**CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF
OUTSIDE PLANT**

For further details, please refer to ITU-T List of Recommendations.

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The approval of Recommendations by the Members of the ITU-T is covered by the procedure laid down in WTSC Resolution No. 1 (Helsinki, March 1-12, 1993).

ITU-T Recommendation L.27 was prepared by ITU-T Study Group 6 (1993-1996) and was approved by the WTSC (Geneva, 9-18 October 1996).

NOTES

1. In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.
2. The status of annexes and appendices attached to the Series L Recommendations should be interpreted as follows:
 - an *annex* to a Recommendation forms an integral part of the Recommendation;
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METHOD FOR ESTIMATING THE CONCENTRATION OF HYDROGEN IN OPTICAL FIBRE CABLES

(Geneva, 1996)

Introduction

Considerable experience has been gained using optical fibre cables in terrestrial and subsea applications showing that optical fibres provide a stable transmission medium.

There are some situations where the concentration of hydrogen within a cable can rise to a sufficiently large value to cause the optical loss of the fibre to increase (see Appendix III). Therefore, there is a need to determine the build-up of hydrogen in a cable by considering the ways that hydrogen can be generated within it.

If the escape of hydrogen through the polyolefin sheath or the overlap of a moisture barrier balances the hydrogen generated in the cable, the resulting concentrations within the cable do not cause a noticeable change in optical loss (see Appendices I and II).

Considering

- a) that hydrogen within a cable can result from:
 - the hydrogen released from the cable components;
 - the electrolytic action between components of different metal in the presence of moisture;
 - the corrosive reaction of metallic components in the presence of moisture;
 - the hydrogen within the air pumped into pressurised cable networks;
- b) that hydrogen can escape by permeation through the cable sheath except for hermetically sealed sheaths of where the external concentration of hydrogen is greater than that within the cable core;
- c) that the optical loss change, which is most noticeable at the wavelength of 1.24 μm and/or 1.38 μm , arises from:
 - a temporary change due to molecular hydrogen within the fibre core which is proportional to the concentration (partial pressure) of hydrogen;
 - a permanent chemical change which depends on the dopant and its concentration, due to hydroxyl formed by the chemical combination of diffused hydrogen molecules and structural defects in the silica glass of the fibre,

it is recommended

- 1) that for cable types which may allow the concentration of hydrogen within the cable core to build up to a value which could cause a noticeable increase in optical loss:
 - i) the concentration of hydrogen anticipated within the cable core should be estimated from a knowledge of the hydrogen released from the components of the cable. If desired, the measurement method of gas chromatography described in Annex A can be used to determine the amount of hydrogen released from the cable components;
 - ii) the concentration of hydrogen in filled cables should be managed by one or more of the following:
 - minimized by careful selection of the components of the cable;
 - reduced to zero by the use, within the cable, of a hydrogen-absorbing material which should have an active life comparable to the life of the cable;
 - have reduced influence on optical performance by the use of hermetically coated fibres or by the use of a hermetic sheath around the cable core in the event of the external concentration of hydrogen being greater than that within the cable core;

- iii) the concentration of hydrogen in unfilled cables should be purged from the cable at regular intervals;
 - iv) lengths of unfilled prototype cable or specially prepared short samples (up to 10 m) of filled prototype cable may be tested to confirm the estimated concentrations of hydrogen by the measurement method described in Annex B;
- 2) that the long-term effectiveness of hydrogen-absorbing material, when used, should be confirmed by the measurement method described in Annex C.

For cables of all dielectric construction, there is sufficient experience of stable transmission properties to make unnecessary the testing for significant concentrations of hydrogen which could cause an increase in optical loss.

Annex A

Measurement of hydrogen released by each cable component by gas chromatography

A.1 Principle

Gas chromatography may be used to estimate the hydrogen concentration. The concentration of hydrogen in a vessel is estimated by comparing the N₂, O₂ and H₂ peaks, measured by gas chromatography, with that of a known hydrogen concentration. Hydrogen release can usually be accelerated by raising the ambient temperature. Such acceleration conditions as temperature and time depend on the volume of the sample. The temperature is usually from 50 °C to 160 °C and the time within 48 h. The elevated temperature should be selected to be below the level which would melt or deform the cable materials. The time should be long enough for the thermal activity to saturate. After thermal activation, the temperature is reduced to its initial level and the hydrogen concentration is measured by gas chromatography. A flow chart, for estimating the amount of hydrogen released in the cable material sample, is shown in Figure A.1.

A.2 Equipment

The basic equipment is shown in Figure A.2. A gas chromatograph is used for the quantitative analysis of hydrogen. It usually measures the hydrogen content by separating hydrogen from the other gasses by virtue of this element's unique retention time in the column and then determining its concentration with a thermal conductivity detector. The usual conditions of such a gas chromatograph are as follows:

- 1) *Column*

Length:	1 to 4 metres
Filter:	Molecular sieve 5A
Temperature:	40 °C to 50 °C
- 2) *Carrier gas (Argon gas)*

Flow rate:	30 to 40 ml/min
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- 3) *Detector (Thermal conductive detector)*

Temperature range for detection:	25 °C to 50 °C
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A.3 Measurement procedures

A.3.1 Sample preparation

Optical fibre cables usually contain components as follows:

- coated silica fibres;
- polymerised materials, such as:
 - tubes or slotted rods in which the coated silica glass fibres may be inserted;
 - wrapping tapes including water-blocking tapes;

- jelly compounds or water-blocking powder which may be used as water-blocking materials;
- metallic, glass fibre or aramid components which may be used as strength members.

The specimen is prepared as a test sample. It should be placed in an extraction-concentration vessel of known volume, which is filled with air or an inert gas such as argon at atmospheric pressure. The vessel is usually made of glass in preference to metal, since metal surfaces provide a site for hydrogen molecules absorption-desorption phenomena which make reliable testing difficult at low concentrations. The vessel must be hydrogen-proof and not itself a source of hydrogen. In some cases, the sample may be put into a glass ampoule which has a smaller volume than the vessel and the mouth of the ampoule sealed to prevent hydrogen leakage during thermal activation. In such cases the inner volume of the vessel or sealed ampoule should be about ten times or more greater than the volume of the sample for the oxidization reaction.

A.3.2 Calibration

The calibrated master line of the gas chromatograph should be determined before measurement. An outline of this procedure is shown in the upper left hand side of the flow chart in Figure A.1. A primary standard of 10 000 ppm of hydrogen in argon is prepared as a master gas that is diluted to the desired concentrations of 10, 20, 50 and 100 ppm. Hydrogen at these concentrations is by a gas chromatograph and the calibrated master line, i.e. the relationship between the gas concentration and the area under the peaks is determined by the least-squares method. Examples of the peaks and the calibrated master line obtained in the calibration are shown in Figure A.3.

A.3.3 Measurement

After the sample is prepared, hydrogen released from the test sample is activated thermally according to the procedure shown in the upper right hand side of Figure A.1. At this stage the sample temperature is raised to a predetermined level between 50 °C and 160 °C. The upper temperature limit should be below the level at which the test sample would melt or deform. The time should be long enough to enable the time required for achieving thermal balance to be disregarded and short enough to ensure a reproducible test. Air is preferable as a reaction atmosphere because optical fibres in service are usually surrounded by air and oxidization affects the hydrogen release from organic materials such as jelly compounds and coating resins. Following this, the sample is returned to room temperature.

0.5 ml of gas from within the vessel or ampoule is injected into the gas chromatograph and the hydrogen concentration is obtained from the master line. When an ampoule has been used, it must be broken in the vessel before taking the measurement. The quantity of hydrogen released from the test sample can be derived by:

$$H_2 = A \cdot \frac{V_2}{V_1} \quad (\text{ml/g or ml/cm, for the weight or the length of test sample})$$

where:

A is the hydrogen concentration obtained from the calibrated master line corresponding to the area under the peaks in the gas chromatograph of the extracted gas

V_1 is the volume injected into the gas chromatograph

V_2 is the internal volume of the vessel

NOTE – Hydrogen in the region of 10^{-5} ml and above can usually be detected by this method.

A.4 Analysis

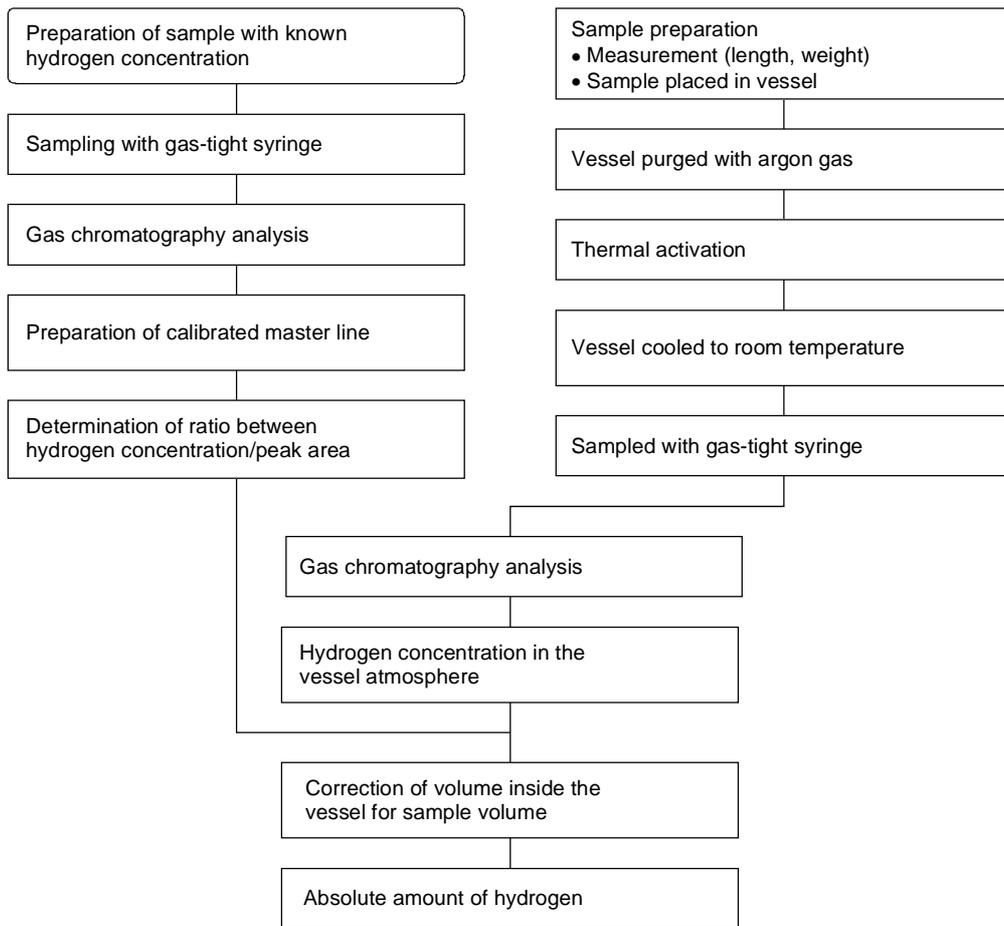
The maximum quantity of hydrogen generated from a test sample at an elevated temperature can be estimated by the measurement described above. The law in the variation of hydrogen release due to temperature variation is considered to follow an Arrhenius representation:

$$\text{Log } [H_2] = f(1/T)$$

where:

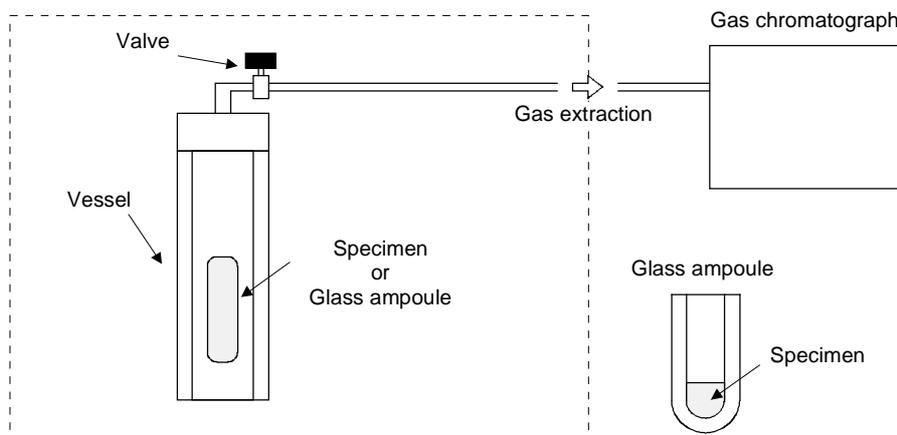
T is the absolute temperature.

The maximum quantity of hydrogen generated from the test sample at the in-service temperature can be calculated by knowing the relationship between the quantity of hydrogen released and the temperature.



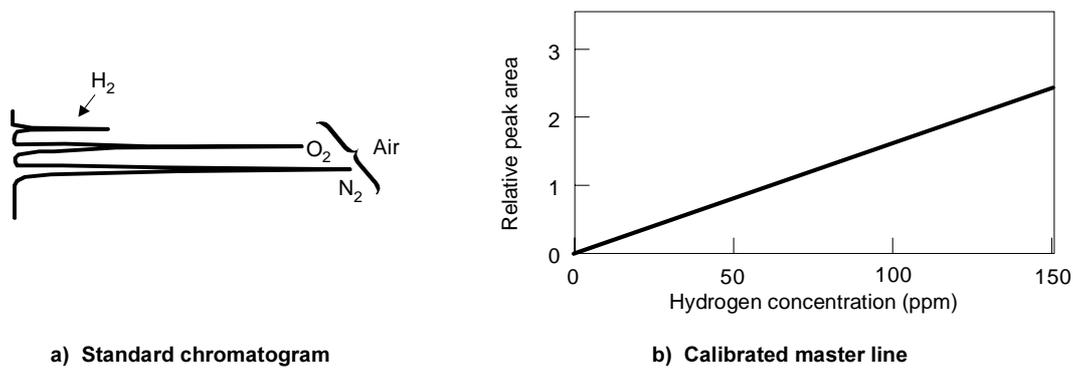
T0603940-96/d01

Figure A.1/L.27 – Flow chart for the measurement of gas chromatography



T0603680-94/d02

Figure A.2/L.27 – Equipment configuration for the measurement of hydrogen derived from cable components



T0603690-94/d03

Figure A.3/L.27 – Examples of a chromatograph and calibrated master line used in the measurement of gas chromatography

Annex B

Measurement of the concentration of hydrogen in a cable sample

B.1 Unfilled cable

B.1.1 Laboratory method

A length of cable is stored in a climatic chamber with its ends sealed. The gas chromatography measuring technique, described in Annex A, is normally used to examine a sample of gas extracted from the cable.

For non-hermetically sealed cable sheaths, the measurement can be carried out on a sample of sheath to determine the rate of the escape of hydrogen by permeation.

B.1.1.1 Sample preparation

In order to seal the cable ends into special cable connectors, a primer is used to bond the cable sheath to the adhesive which is applied to each of the metallic cable connectors. To check the gas tightness of the test apparatus, it is first connected to a length of polymer coated seamless metallic tube with a set of cable connectors bonded to each end.

B.1.1.2 Measurement

After the cable has stabilized to the temperature in the environmental chamber, a sample of gas is drawn out of the cable and the hydrogen concentration is measured. The measurement is repeated.

B.1.2 Field method

The hydrogen concentration can be measured directly using a fuel cell technique, for example, a portable *Exhaled hydrogen monitor* manufactured for medical use. Where the cable is pressurized, it is possible to measure the concentration of hydrogen by monitoring the gas drawn off at a series of sheath closures along the cable route from valves which form part of the cable pressurization arrangements. A known concentration of hydrogen-air mixture is used to calibrate the monitor.

B.2 Filled cable

The concentration of hydrogen in the internal cable environment is determined by the collection of representative samples in drain tubes fitted within a length of prototype cable and measuring these in accordance with B.1.1.

Tubes, which are small enough not to disturb the internal cable permeable atmosphere, are inserted into the cable core during the manufacture of the cable. Usually, two drains are inserted to keep the volume sampled to less than 1% of the total internal permeable cable volume.

Annex C

Measurement of the long-term effectiveness of hydrogen-absorbing materials

C.1 Principle

A test is required that will demonstrate that hydrogen-absorbing material is capable of absorbing hydrogen by a chemical process throughout the service life of a cable. The test should show that the rate of absorption remains stable with time in order that the amount of getter required to protect the cable can be evaluated.

The test is carried out by placing a known quantity of getter into a closed volume, degassing the material, introducing hydrogen at a known pressure and measuring the absorption of hydrogen by the reduction in pressure after a set period of time. The test is repeated after accelerated ageing of the getter to show a steady rate of absorption. A temperature of 105 °C for one month represents 20 years at ambient temperature if a value of 11 kcal/mole is assumed as the activation energy of the ageing process.

C.2 Apparatus

The apparatus consists of a metallic container with vacuum tight valves that can be evacuated and filled with hydrogen gas. A pressure transducer continuously monitors the internal pressure.

C.3 Measurement procedures

- Weigh the sample holder to an accuracy of 0.1 g.
- Spread 100 ± 1 g of getter uniformly into the sample holder and re-weigh.
- Insert the sample holder and seal the apparatus.
- Degas for 24 h at less than 10 Pa.
- Introduce hydrogen at 60 kPa.
- After 24 h, note the hydrogen pressure and temperature.

C.4 Analysis

The absorption of hydrogen is expressed as ml of hydrogen at STP per gramme of compound and is calculated from the following:

$$\text{Hydrogen absorbed} = \frac{273(P - P_r)V}{1013(273 + T_r)M}$$

where:

P is the initial pressure in 100 Pa

P_r is the hydrogen pressure after 24 h

T_r is the temperature (°C)

V is the volume of the apparatus (ml)

M is the getter weight in grammes

Appendix I

UK experience of hydrogen concentrations in moisture barrier optical fibre duct cables

I.1 Field experience

There is practical experience to be drawn from more than 1×10^6 km of optical fibre installed in the United Kingdom since the late 1970s. The cables contain an aluminium laminate tape moisture barrier and many of the early cables were unfilled and pressurized. It has therefore been possible to measure the hydrogen concentration in cables installed for several years in ducts by monitoring drawn off gas from within the cables. The concentration of hydrogen was measured using a portable *Exhaled hydrogen monitor* described in Annex B. The peak value recorded for the hydrogen concentration in duct cables is 400 ppm (1). There have been no reports of any detectable rise in optical loss with such concentrations of hydrogen within the cables.

I.2 Analysis

When solubility effects are ignored, the partial pressure of hydrogen within the moisture barrier screen is given by:

$$P = \frac{H}{Q} \left[1 - \left(1 - \frac{P_0 Q}{H} \right) \exp \left(- \frac{Q \cdot t}{V_0} \right) \right] \quad (1)$$

where:

- P is the partial pressure of hydrogen (atm)
- P_0 is the original partial pressure of hydrogen (atm)
- H is the hydrogen evolution rate (ml/cm · s)
- Q is the hydrogen escape rate through the barrier (ml/cm · s)
- t is the time in seconds
- V_0 is the free volume per unit length of cable (ml/cm)

Assuming that H is not variable and the time constant V_0/Q is short compared with the lifetime of the cable, the concentration of hydrogen within the cable for the service period will asymptotically tend to:

$$P = \frac{H}{Q} \quad (2)$$

as shown in Figure I.1.

Considering a cable construction having a moisture barrier which consists of a longitudinal aluminium laminate tape applied with an overlap of at least 6 mm. The aluminium tape is coated on one side with polymer 40 μm thick. The heat of extrusion of the polyethylene sheath seals the overlap producing a 40 $\mu\text{m} \times 6$ mm channel through which hydrogen can diffuse. This is the most significant route for hydrogen to escape since the diffusion through 150 μm of aluminium tape is very much slower.

Q can be measured directly. Nitrogen containing a known percentage of hydrogen is passed through cable samples, each surrounded by a sealed copper tube. The level of hydrogen is monitored as a function of time. By selecting a number of test samples of different length, it is possible to eliminate end effects and reduce the possibility of a freak defect in the construction of the overlap in a test sample.

At 20 °C, the diffusion rate through the moisture barrier with a perfectly formed overlap is calculated to be:

$$Q = 6.1 \times 10^{-10} \text{ ml/sec.atm.cm}$$

As the overlap is not perfectly formed along the cable, the average value of the diffusion rate obtained from measurements is:

$$Q = 3.7 \times 10^{-8} \text{ ml/sec.atm.cm}$$

If the average temperature of installed cable is 5 °C, this average diffusion rate, when corrected to the field temperature, becomes:

$$Q = 1.58 \times 10^{-8} \text{ ml/sec.atm.cm}$$

The hydrogen evolution rate, which depends mainly on the hydrogen released by the corrosion of the aluminium tape, is determined from measurement to be:

$$H = 1.5 \times 10^{-11} \text{ ml/sec.atm.cm}$$

Substituting in Equation (2) gives the theoretical partial pressure of hydrogen to be:

$$P = 1.5 \times 10^{-11} / 1.58 \times 10^{-8} = 949 \text{ ppm}$$

The field value recorded of 400 ppm is much lower because there will always be some gas flow in a static pressurized system caused by leakage.

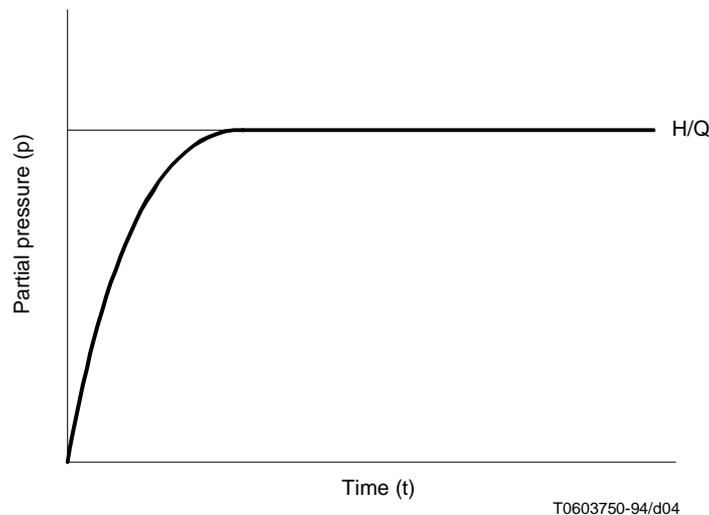


Figure I.1/L.27 – Partial pressure of hydrogen as a function of time for a typical cable sampe

I.3 References

- HORNUNG (S.), CASSIDY (S.A.), REEVE (M.H.) The distribution of H₂ gas along an inland optical fibre cable. Symposium of Optical Fibre Measurements 1984, *National Bureau of Standards*, NSB-SP-683, pp. 85-88, October 1984.

Appendix II

Japanese experience of the loss increase due to hydrogen generation in water-blocking tape optical fibre cable

II.1 Structure and materials of the water-blocking tape cable

To assure the long-term stability of optical fibre cable characteristics, it is important to prevent water penetrating into the cable and hydrogen generation inside the cable. Water-blocking cable has been developed in which water-blocking tapes are wrapped around each slotted rod and also the cable core. Such cables are easy to manufacture and handle. The water-blocking tapes swell when they absorb water and form a kind of dam to prevent water penetration. Water can be stopped within 3 m of entry. Long-term stability with regard to optical loss increase requires checking because of the possible wetting of a short section of cable.

A cross-section of the cable, given in Figure II.1, shows the slotted rods stranded around a central strength member. Each slotted rod is composed of a central steel wire embedded in polyethylene. Optical fibre ribbons are tightly inserted into each slot, and the rod is wrapped with water-blocking tape. A wrapping of water-blocking tape is applied to the laid-up rods and a polyethylene sheath is applied overall. All steel wires are covered with a thin coating of copper. The water-blocking tapes and the coatings of the optical fibre ribbons are made from materials which generate little hydrogen.

II.2 Hydrogen generated from cable components

The amount of hydrogen generated by the ribbon coatings, the steel wires and the water-blocking tape were measured in accordance with Annex A. Both dry tapes and those which had absorbed artificial sea water were measured. The hydrogen generated for the different materials per cm^2 at 80°C is shown in Figure II.2.

II.3 Evaluation of loss increase due to hydrogen generation

Optical loss increases due to hydrogen can be classified into two types:

- that due to hydrogen molecules (H_2);
- that due to hydroxyl (OH).

The optical loss increase due to H_2 is a reversible phenomenon and is proportional to the partial pressure of the hydrogen in the optical fibre cable. The quantity is given by

$$L_{\text{H}_2}(\lambda) = C_{\text{H}_2}(\lambda) \cdot e^{2.24/RT} \cdot p \text{ (dB/km)} \quad (1)$$

where:

R is the gas constant, with a value of 1.986×10^{-3} (kcal/mol \cdot $^\circ\text{K}$)

T is the absolute temperature ($^\circ\text{K}$)

p is the partial pressure of hydrogen in the cable

$C_{\text{H}_2}(\lambda)$ is a coefficient dependent on wavelength (λ) and is the same for both single-mode and multimode optical fibres since it does not depend on dopant concentrations.

The values of $C_{\text{H}_2}(\lambda)$ at $1.31 \mu\text{m}$ and $1.55 \mu\text{m}$ are estimated to be 0.0102 and 0.0195 respectively, making the loss increase at $1.55 \mu\text{m}$ nearly double that at $1.31 \mu\text{m}$.

Optical loss due to OH is irreversible and time dependent. The quantity $L_{\text{OH}}(\lambda)$ is given by

$$L_{\text{OH}}(\lambda) = C_{\text{OH}}(\lambda) \cdot e^{-10.79/RT} \cdot p^{0.5} \cdot t^{0.38} \text{ (dB/km)} \quad (2)$$

where:

t is the time in hours

$C_{OH}(\lambda)$ is a coefficient dependent on wavelength and is different for single-mode and multimode fibres since it depends on dopant concentrations. The values at 1.31 μm and 1.55 μm for single-mode optical fibre are estimated to be 2.1×10^4 and 1.7×10^5 respectively.

The partial pressure, p , can be estimated from the volume of cable in which the hydrogen can diffuse and from the measurements of hydrogen generated in the cable components.

The calculated increases in loss at room temperature for 20 years is summarized in Table II.1.

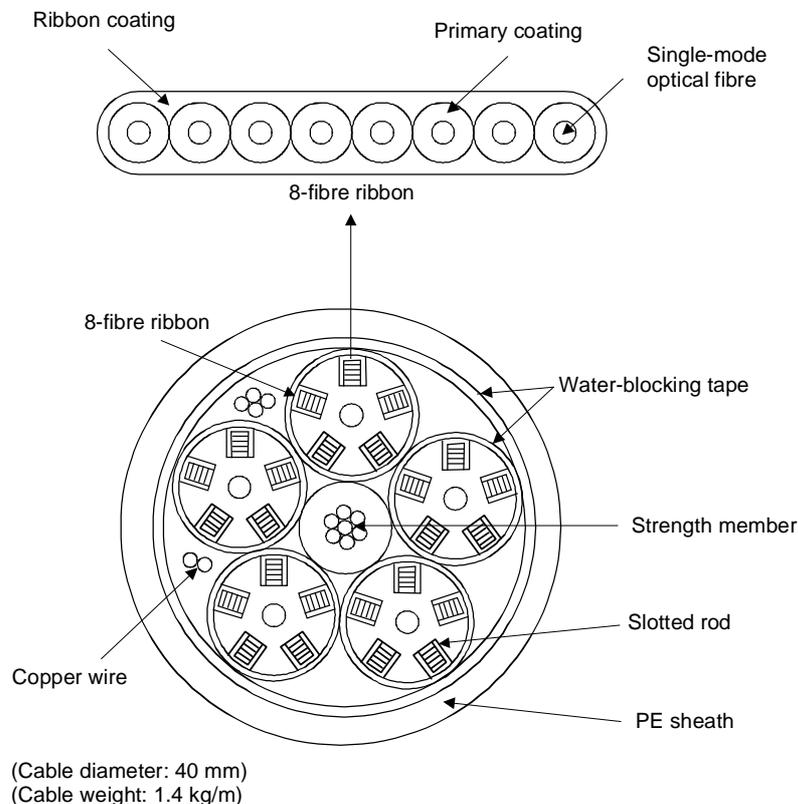
Table II.1/L.27 – Calculated increase in loss for single-mode optical fibre

Wavelength	In air		In water	
	1.31 μm	1.55 μm	1.31 μm	1.55 μm
L_{H_2}	0.0001	0.0003	0.0000	0.0001
L_{OH}	0.0005	0.0027	0.0002	0.0016
Total	0.0006	0.0030	0.0002	0.0017

The excess loss is estimated to be less than 0.005 dB/km at both 1.31 μm and 1.55 μm .

II.4 Increase in loss in water-penetrated cable

In order to investigate the long-term stability of water-penetrated cable, water was pumped through a 50-m length of cable which was then held at 60 °C in a test chamber at 90% RH. Twenty fibres in a slot were spliced into a 1-km length. The results of optical loss measurement are shown in Figure II.3. No increase in loss at 1.24 μm was detectable after five months. A reduction in loss at 1.55 μm suggests some relaxation in the fibre packaging during this period.



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Figure II.1/L.27 – 1000 fibre water-blocking optical fibre cable

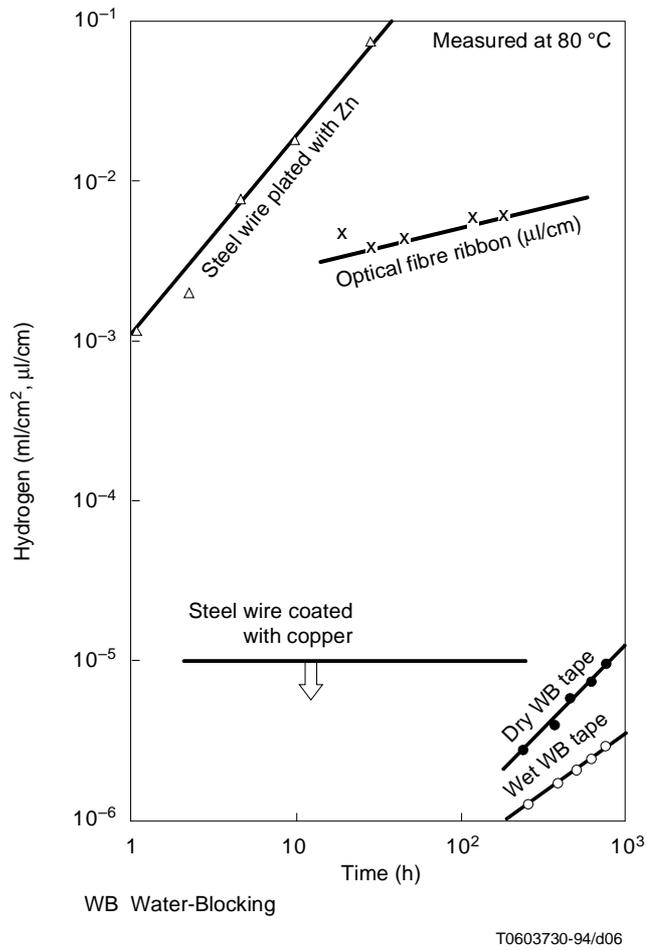


Figure II.2/L.27 – Hydrogen generated from various cable materials

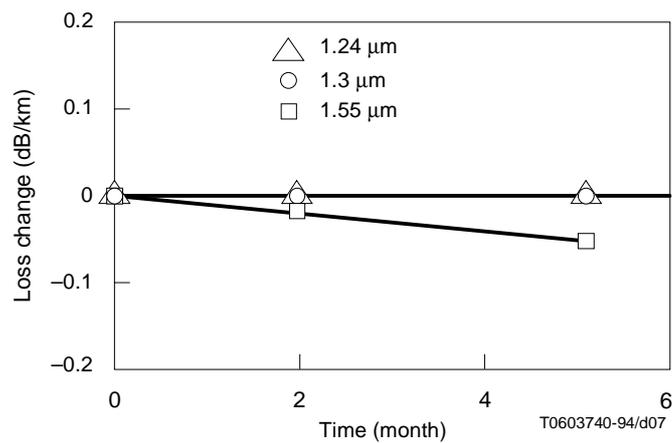


Figure II.3/L.27 – Change in loss of wet water-blocking cable at 60 °C and 90% RH

Appendix III

Spanish experience of hydrogen generation in moisture barrier optical fibre cables

III.1 Cable structure

Between 1985 and 1990, Telefónica installed single-mode optical fibre cables which were constructed with a copolymer-aluminium moisture barrier and a stranded galvanized steel central strength member. All these cables were jelly-filled.

III.2 Field experience

Even though our field experience showed us that for these cables hydrogen concentration is not important, we have in some cases found installed cables where the hydrogen concentration was sufficient to produce increases in attenuation on all fibres in the cable, both in the second and third transmission windows. The maximum measured increase of attenuation was 0.3 dB/km in the second window and 0.6 dB/km in the third window, corresponding to hydrogen partial pressure around 1 atm in the cable core.

Figure III.1 shows the spectral attenuation of a fibre in a faulty cable (affected by hydrogen).

III.3 Origin of the problem

After carrying out several tests, we concluded that the problem was due to the presence of water or humidity, within the cable, in contact with the galvanized steel strength member.

The most probable hypothesis is that the cables were manufactured in bad conditions (with a high water or humidity content) or the galvanized steel was not adequately treated.

III.4 Problem solution

A method to eliminate the hydrogen has been used with success in laboratory tests. The method consists on the connection of the galvanized steel strength member (in our case coated with polyethylene) to a dry air source at 5 atm pressure (see Figure III.2). After several weeks (between 2 and 8, depending on the cable length), the hydrogen level was reduced to insignificant values. Four months after the dry air had been disconnected, no new hydrogen generation had been detected.

Figure III.3 shows the spectral attenuation decrease in a 1150-m length cable during the four weeks after connection to the dry air source.

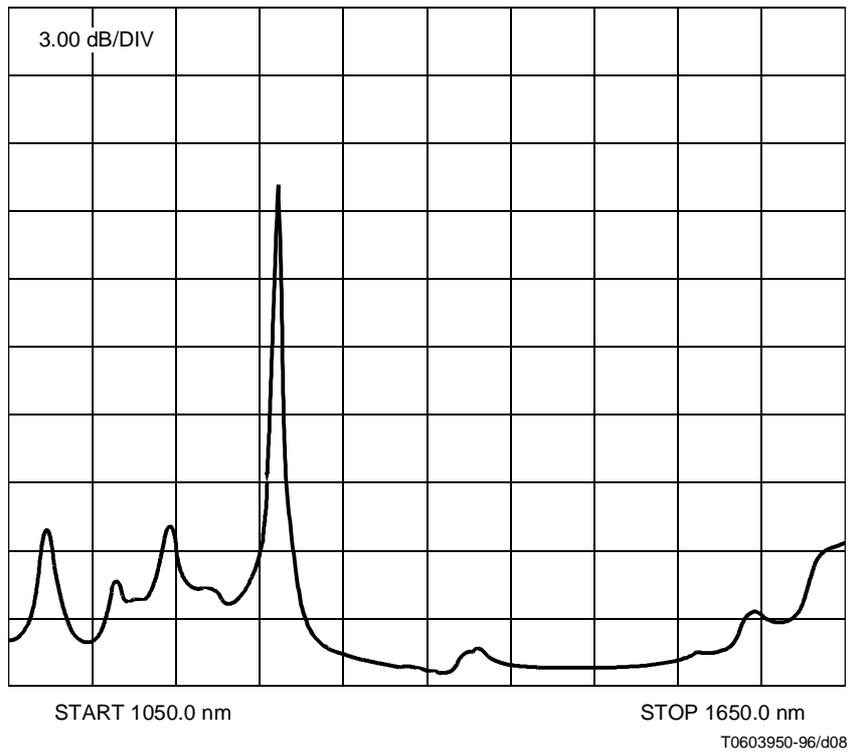


Figure III.1/L.27 – Spectral attenuation of a fibre in a 1920-m length of faulty cable (affected by hydrogen)

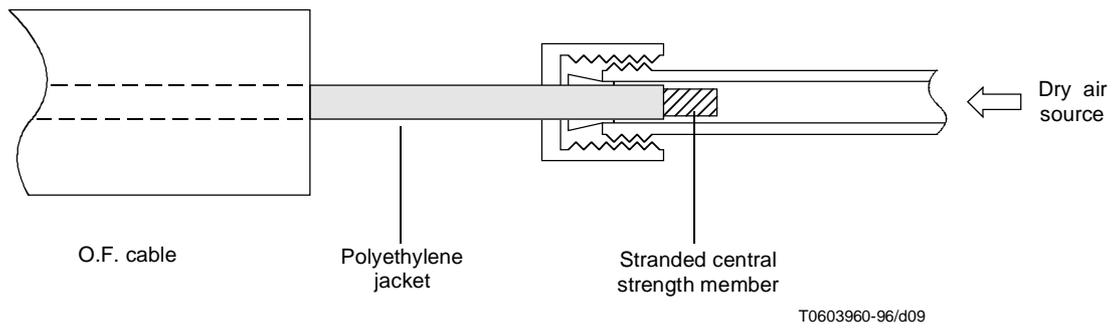


Figure III.2/L.27 – Cable connection to the dry air source

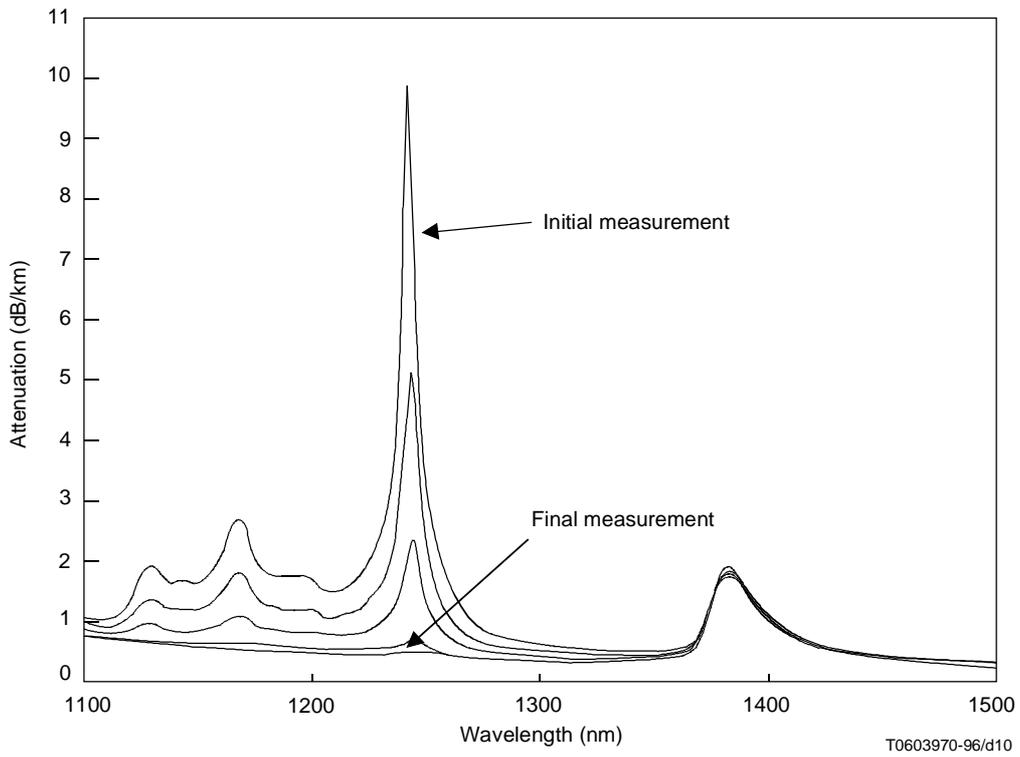


Figure III.3/L.27 – Spectral attenuation decrease in a 1150-m cable during four weeks after the introduction of dry air

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