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Meeting Paper

SMRI Reference for External Well Mechanical Integrity Testing / Performance, Data Evaluation and Assessment

Summary of the Final Project Report – SMRI Research Report 94-0001

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0 Abstract

Verifying the external mechanical integrity of storage cavern wells based on interface tests is current standard engineering practice. There are, however, a number of different procedures applied to performing and, in particular, assessing such tests. For this reason, the Solution Mining Research Institute (SMRI) commissioned a research project aimed at developing a reference test, with the objective of providing future comparability between the various test alternatives and the assessment thereof. This report summarizes the results of the SMRI project (Report no. 95-0001-S).

The various test methods can be divided into three groups:

(1) In-Situ Balance (referred to in the USA as the Nitrogen Interface Test)

(2) In-Situ Compensation

(3) Above Ground Balance

In present testing it is usual to assess the tightness of the well by comparing the theoretically determined leak rate with the measurement accuracy, the minimum detectable leak rate (MDLR): if the theoretical value falls within the MDLR, then the well is classified as *technically tight*.

In order to determine the assessment criterion for the SMRI reference value, the achievable measurement accuracy of the widely used In-Situ-Balance Method was taken as the basis, assuming a typical gas cavern configuration (13-3/8" last cemented casing, setting depth 1000 m, cavern throat diameter 1 m). The MDLR is approx. 40 kg with nitrogen test medium. A precondition for this value is the use of accurate, standard pressure sensors and the depth-dependent calculation of the mass of the shut-in test gas.

Experience gained at many wells and over many years in the execution of this test - even with shut-in periods of only 24 hours (USA) - is that, to date, there is no evidence of any hazard to safety above ground, contamination of the underground, or loss of product where the theoretical leakage rate has been equal to or less than 40 kg/24 h. Taking this as a basis, the value was rounded up and developed into the SMRI Reference Value of 50 kg (N_2)/24h as the specification for test accuracy (MDLR).

Assuming a ratio of at least 3:1 between the smallest reliably detectable measurement value and the measurement accuracy, the *maximum admissible* reference leak rate (MALR) is then:

$$\text{MALR} = 3 * \text{MDLR} = 150\ \text{kg}(N_2)/24\ \text{h}.$$

1 Introduction

Verification of the mechanical integrity of access wells is a prerequisite for safe and economical operation of storage caverns, because leakage can result in contamination of groundwater, represents a risk to the surface and can result in substantial loss of product.

In this study, a differentiation is made between the *internal* integrity of the access well (tightness of valves, casings, connectors, cementation within the last cemented casing) and *external* integrity (tightness of the cavern including transition zone from the cased to the open welll).

The focus of this SMRI project is on the verification of the external integrity of the access wells, in particular of storage caverns.

For many years it has been standard practice worldwide in the construction of storage caverns to use an interface test to verify the integrity of the cavern well (see Fig. 1). There is a broad range of different procedures and, in particular, of the criteria for evaluating results.

The SMRI responded to this situation by initiating an R&D programme aimed at providing a set of standard procedures, based on up-to-date technology, with the intention of providing an engineering approach for practical use by the industry and its regulators. The SMRI membership expected to gain the following:

- comparability between methods and assessments
- influence on the movement towards standardization by regulators
- establishment of a firm technical base in the event of litigation (accidents etc.) between the operator and other parties.

However, it became apparent during the course of the investigations that the SMRI could not stipulate national or even international *standards*. The objective was therefore re-targeted towards providing

- an overview of current practice
- development of an SMRI *reference* for external well mechanical integrity testing with respect to performance, data evaluation and assessment.

The intention was to provide test companies and operators with a platform from which they could perform and, in particular, compare their tests with international standard practice - with the selection of the actual method remaining their responsibility.

The investigations concentrated on those tests which provide a *quantitative* statement as to the tightness of the final casing and the cementation against the rock mass. These *interface tests* are mainly characterized by the injection of a limited volume of test fluid - which is lighter than the liquid in the cavern at the time of the test - into the annulus of the access well, followed by the evaluation of various parameters such as pressure and interface depth versus time, to allow some statement to be made as to the integrity of the well.

2 Cavern integrity testing

Mechanical integrity of a storage cavern can be defined as:

> *technical tightness of the casing, tubing, and the packer, and no fluid movement either along the cementation or into formations adjacent to the well bore.*

This is intended to

- protect the ecosystem from uncontrolled escape of product
- assure safety of personnel and surface installations
- achieve loss-free storage.

As referenced in the introduction, the study is focused on the verification of *external* integrity, especially of the access well in the particularly sensitive transition zone from the open well to the cemented cased well where the risk of leakage is at a maximum, because of the different materials which interface at this point (rock salt, cement, steel) which are all subject to the same mechanical stress levels.

Focusing the tests on the well as opposed to the cavern as a whole leads to a substantial improvement in the accuracy of verification, because the volume of the well is generally less than that of the cavern by three or four orders of magnitude.

3 Current standard practice

3.1 Minimum detectable versus maximum admissible leak rate

A prerequisite for realistic assessment of the external integrity of an access well is the quantitative assessment of tightness. In comparison, the meaning of qualitative methods, e.g. observing the pressure loss of a shut-in well, is very limited.

In the past, the measure for the quantitative assessment of tests was the *accuracy* of the pertinent test procedure (minimum detectable leak rate - MDLR): If the results were within measurement accuracy, then the well was classed as being technically tight.

As far as hazards above and below ground are concerned, however, it is not the minimum *detectable* leak rate which is of importance but the maximum *admissible* leak rate (MALR). Therefore the strategic objective of the SMRI research project was to develop a reference value for MALR.

3.2 Comparing the test methods; introduction

All the test methods described below have the following in common:

- liquid filled cavern
- injection of a test medium lighter than and immiscible with the product.
- test pressure near to maximum pressure.

The basic differences are related to:

- area tested
- equipment and procedure
- test fluid
- MDLR and MALR.

In order to be in a position to compare the accuracy (MDLR) of the various methods, a model cavern was configured reflecting the layout of a typical gas cavern in a salt dome, see Fig. 1.

3.3 In-Situ Balance Method

The In-Situ Balance Method is by far the most frequently used method, and, in the USA, is usually referred to as the Nitrogen Interface Test (see Fig. 2).

The procedure for this method is as follows:

- injection of test gas in the annulus to below the final casing seat
- shutting in the gas
- periodic measurement of head pressure, gas-product-interface depth and possibly temperature and subsequent calculation of shut-in mass of the test gas
- evaluate changes to the shut-in mass of the test gas

The advantage of this method is its straightforward and simple evaluation. Disadvantages are low accuracy at large open hole diameters, (due to the interface depth determination by logging) and the logging costs.

3.4 In-Situ Compensation Method

This method was developed by UGS (German KBB subsidiary). The special features of this test are the use of special test equipment which allows the test gas volume to be reduced and, above all, the fixing of the gas-product-interface at a defined depth, see Fig. 3.

Along standard lines, the test gas is injected into the annulus, until it reaches the weep-hole in the inner pipe. Minute amounts of gas rising to the surface within the drill pipe, indicates that the interface position is at the weep-hole. If, after shutting in, the gas pressure changes in the cavern or a leak will result in the interface depth rising, then the level is reset by injecting additional gas. The amount of gas can be measured with great precision at the surface.

The advantages of this method are: (1) the substantial improvement in measurement accuracy (which for the most part is no longer dependent on the diameter of the open hole), (2) the upper section of the final casing is protected from pressure loads by the test gas; and (3) the calculation of loss rates is quasi continuous. This final aspect enables any trends in the development of the leak rate to be determined, and hence, under certain circumstances, allows the test period to be curtailed.

Disadvantages are primarily the high costs for the installation of the test equipment and the need for a workover unit throughout the entire test period.

3.5 Above Ground Balance Method

The principle behind this method is comparison at the surface of the injected test fluid and the test fluid volume recovered after the test, see Fig. 4. The fact that the volume measurement can be carried out at the surface with great accuracy pre and post test means there is no need to perform measurements below ground and so costs are reduced.

In the mid-eighties, this method using nitrogen was patented in the USA. In practice, however, gas oil is generally used today.

The advantages of this method are simple installation, no need for well logs and straightforward test evaluation. Also the use of gas oil, a liquid, helps reduce the pressure on the final casing in the upper section of the well.

The disadvantages of using gas oil are the reduced measurement accuracy and the possible source of error due to mixing with unrecovered blanket fluids.

3.6 Comparison of accuracy

Fig. 5 provides a comparison of the measurement accuracy of the three methods described. The basis for these values are data drawn from the model cavern (typical hp-gas cavern in a salt dome) shown in Fig. 1. Because the test accuracy of the various methods is initially time independent, an absolute minimum detectable leak is specified rather than a rate. The minimum detectable leak rate is then derived by dividing by the test period (shut-in time). The comparison clearly highlights the high accuracy of the In-Situ Compensation Method (ISC) and the great dependency of the In-Situ Balance Method (ISB) on the diameter of the well.

4 SMRI-Reference Value

4.1 General

As mentioned above, there is a contradiction between the distribution and the importance of the cavern integrity tests on the one hand, and the range of different methods used in carrying out the tests, in particular, evaluation and assessment on the other.

As soon at it became clear that the setting of standards, of guidelines, or even merely recommendations, was unrealistic, the study was restricted to providing a reference with regard to performance, data evaluation and assessment. Reference means that both operators and contractors are able to assess the individual tests by comparing results with current standard engineering practice. They are still free to select their preferred method.

In defining a reference, no preference was given to any specific method, instead a list of basic requirements was established with respect to:

- time of test (before start or after end of solution mining)
- adequate waiting period before testing
- variables to be evaluated (pressure drop, volume, or mass loss of test medium).

As far as the important matter of determining the evaluation assessment criterion (maximum admissible leak rate - MALR) is concerned, two principally different approaches are available: the scientific and the pragmatic approach:

Determining the assessment criteria *scientifically* would involve establishing a quantitative relationship between leakage rate and effects on the hydrosphere and biosphere, safety and economic consequences and the assessment of such interactions. This approach would, therefore, require comprehensive modeling and assessment, whereby the results would be site-specific, and, as such, non-transferable. Because of the disproportionate amount of effort involved, this procedure was dropped.

The alternative is then the *pragmatic* approach. The main basis for this is the positive experience gained in the performance of gas interface tests over a period in excess of 10 years.

Basis for reference MDLR: The majority of interface tests carried out are based on the In Situ Balance Method. Using standard instruments and evaluation methods, a *time-independent* MDL (Minimum Detectable Leak) for the model cavern (see Fig. 1) is calculated to be

$$\text{MDL} = 37 \text{ kg} \approx 40 \text{ kg } (N_2)$$

The mass of 40 kg corresponds to 0.2 m^3 geometrical volume at 170 bar and 300 K. In the case of using more viscous test fluids like LPG or gasoil, the MDLR increases by a factor of approximately 2 to 3. For more details see the complete SMRI-report.

A typical 24 hr and a 48 hr test period would result in MDLR (Minimum Detectable Leak Rates) of

$$\text{MDLR} = 40 \text{ kg/d } (N_2) \quad @ \ \Delta t = 24 \text{ h test duration}$$

$$\text{MDLR} = 20 \text{ kg/d } (N_2) \quad @ \ \Delta t = 48 \text{ h test duration}$$

This value for the MDL of 40 kg (N_2) is based on the evaluation of questionnaires sent to storage cavern operators worldwide: By maintaining this accuracy, all caverns which were deemed to be technically tight based on the results of one of the three test methods discussed (in accordance with current engineering practice), were able to fulfill the following conditions for cavern well integrity:

- no detectable contamination of the hydro- or biosphere;
- protection of subsurface installations;
- safety on surface;
- no detectable loss of product.

4.2 Proposal

4.2.1 Objective, requirements on method, performance

The *objective* of the reference test is the verification of the external mechanical integrity of the cavern well. The area covered is related to final casing (partial), cement bond in casing shoe area and uncased well. The interface test is to be performed after the end of solution mining and prior to the start of storage operations[1].

With respect to the *requirements on method,* reference is only made here to the use of appropriate pressure sensors as essential for quantitative evaluation in terms of mass versus time, or at least volume versus time. Indirect methods without running interface logs and based only on monitoring of the pressure drop per time, are not recommended.

Test *performance*: Geometrical data of the uncased well should be acquired, preferably using sonar or caliper logs. Also possible is indirect determination by injecting the test medium into the uncased well; the test medium should be injected close to the average well temperature; the test should consist of at least three independent measurements.

4.2.2 Minimum Detectable and Maximum Admissible Leak Rate

Normally, in measuring technology, the admissible value is first defined, and then based on this, the necessary accuracy of the method is defined. In order to be able to determine a sensible limiting value, it is necessary to ensure that the value for the accuracy is at least a factor of 3 below the criterion itself.

In this case the problem lies in the fact that previous statements were almost exclusively restricted to the accuracy of the method but not to the limiting value, or did not appreciate the essential difference between accuracy and limiting value.

It was thus necessary to put the cart before the horse" when establishing the reference values for MDLR and MALR:

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[1] repeating the test during operations is up to the operator or regulator

Step 1: Determination of the reference MDLR based on calculations and practical experience

Step II: Determination of the MALR in relation to the reference MDLR

Minimum Detectable Leak Rate (MDLR)

In previous sections, the positive experience with the widely used In-Situ Balance Method was described. Using the parameters from the model cavern (Fig. 1), a theoretical Minimum Detectable Leak Rate of MDLR $\approx$ 40 kg/day (N_2) was calculated. From the underlying principles in its determination, the following SMRI reference MDLR is proposed as the value:

Reference MDLR = 50 kg/d based on nitrogen as the test medium.

Maximum Admissible Leak Rate (MALR)

Based on the reference MDLR of 50 kg/d recommended in the previous section, and the constraint that the smallest possible reliably determinable measured value must be at least a factor of 3 larger than the measuring accuracy, then this gives the following value for the Maximum Admissible Leak Rate:

MALR = 3 * MDLR = 3 * 50 kg/d = 150 kg/d

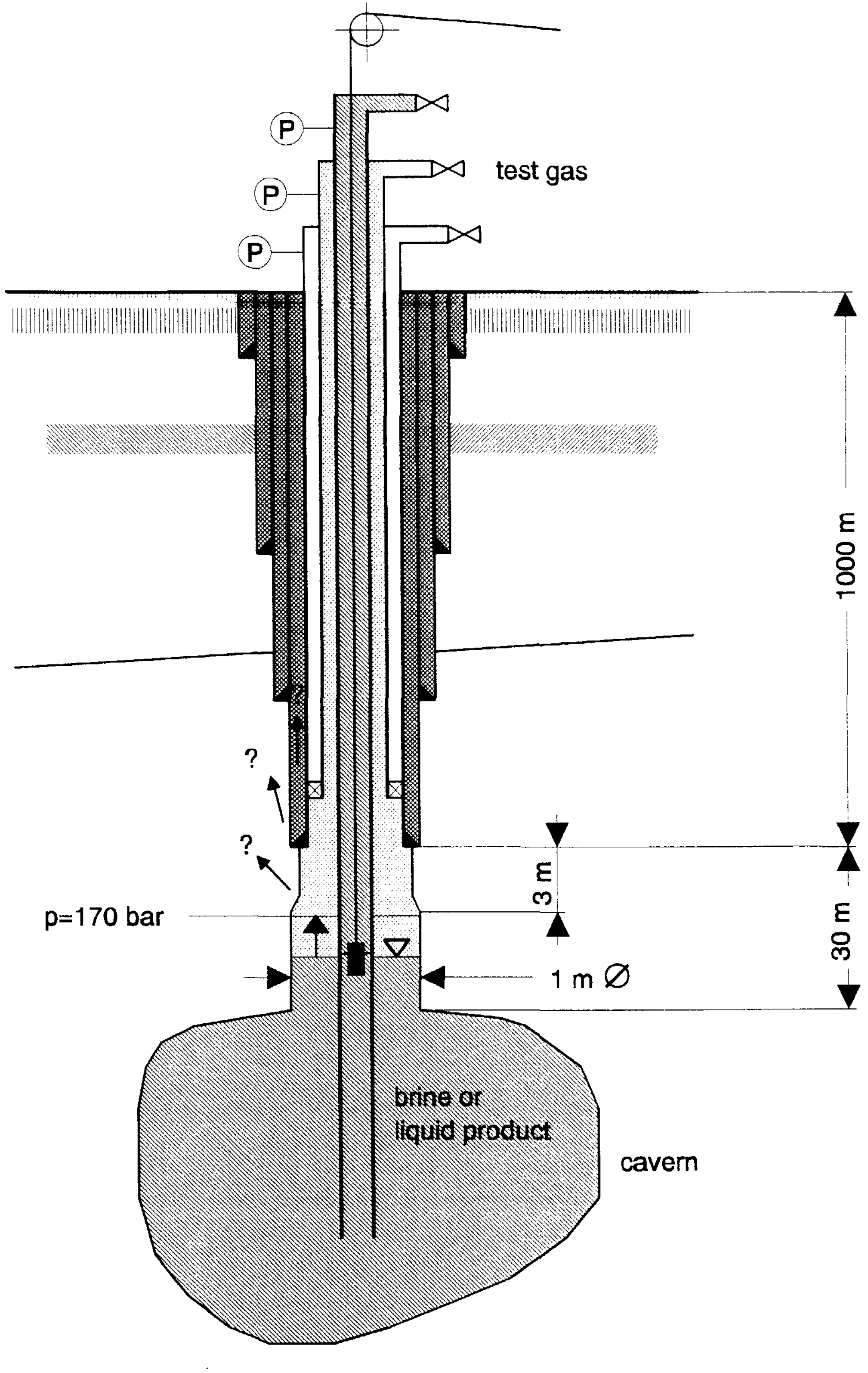
Reference MALR = 150 kg/d based on nitrogen as the test medium.

The mass of 150 kg corresponds to 0.8 m^3 geometrical volume at 170 bar and 300 K.

The above statements on MDLR and MALR were based on nitrogen as test fluid because of its low viscosity and, thus, small MDLR which is equivalent to high sensitivity. The possible hazard resulting from a leak must reflect the leakage rate of the specific product and not the test fluid. In other words, the *admissible* value must be converted to the rate for the product itself.

The reference MALR of 150 kg/d described above refers to nitrogen gas as the test medium. The actual MALR for more viscous storage products (LPG, gas oil, crude oil) is *reduced* by the following factors depending on the product:

• LPG	2
• gas oil	3
• crude oil	10 .



KBB

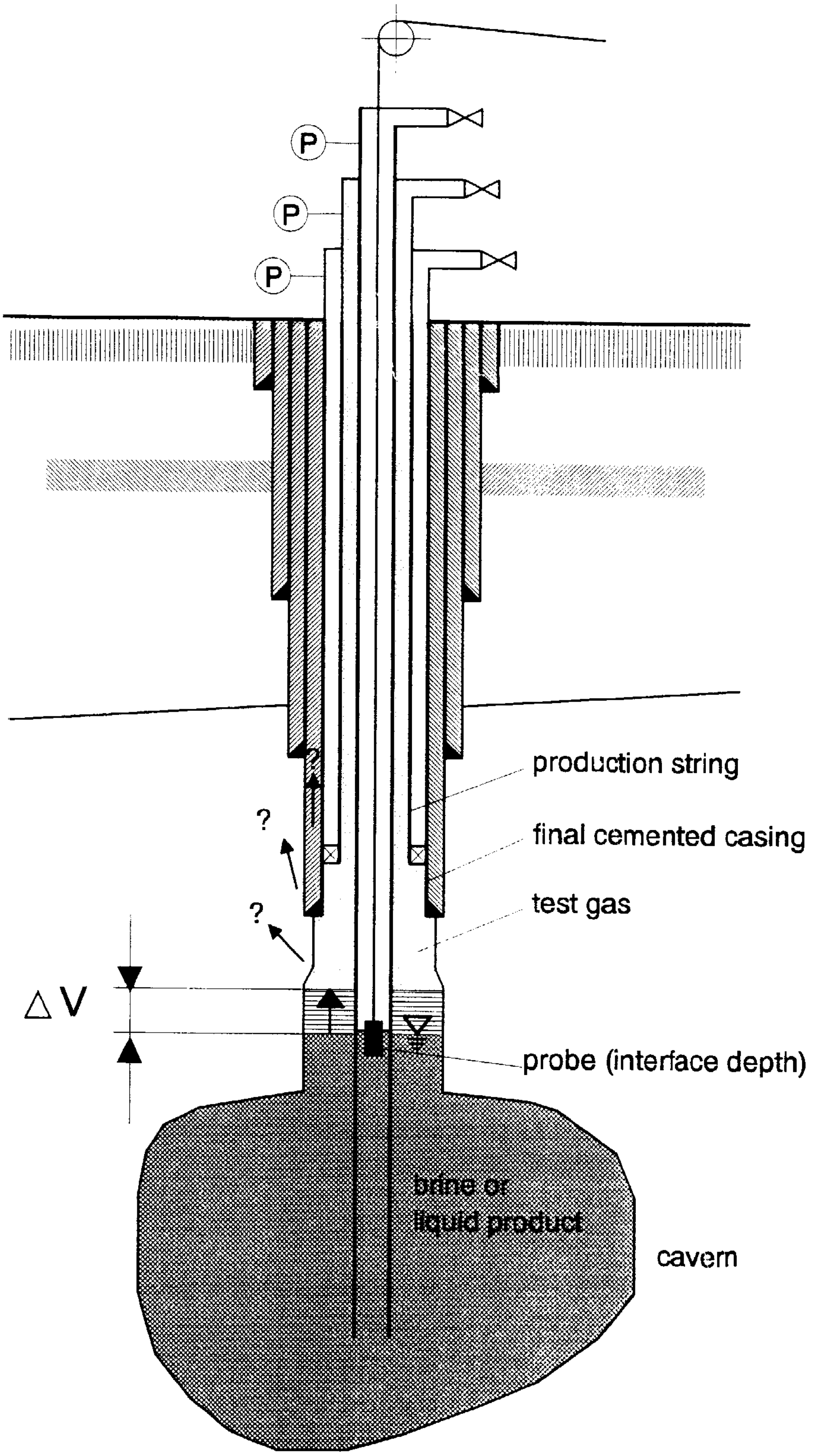
SMRI R&D project
Reference for EWMIT

Fig.
1

444.2100

Interface Test
Model Cavern Well

Feb 95
Cro / OR



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SMRI R&D project
Reference for EWMIT

Fig.
2

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In-Situ Balance Method
(ISB Method)

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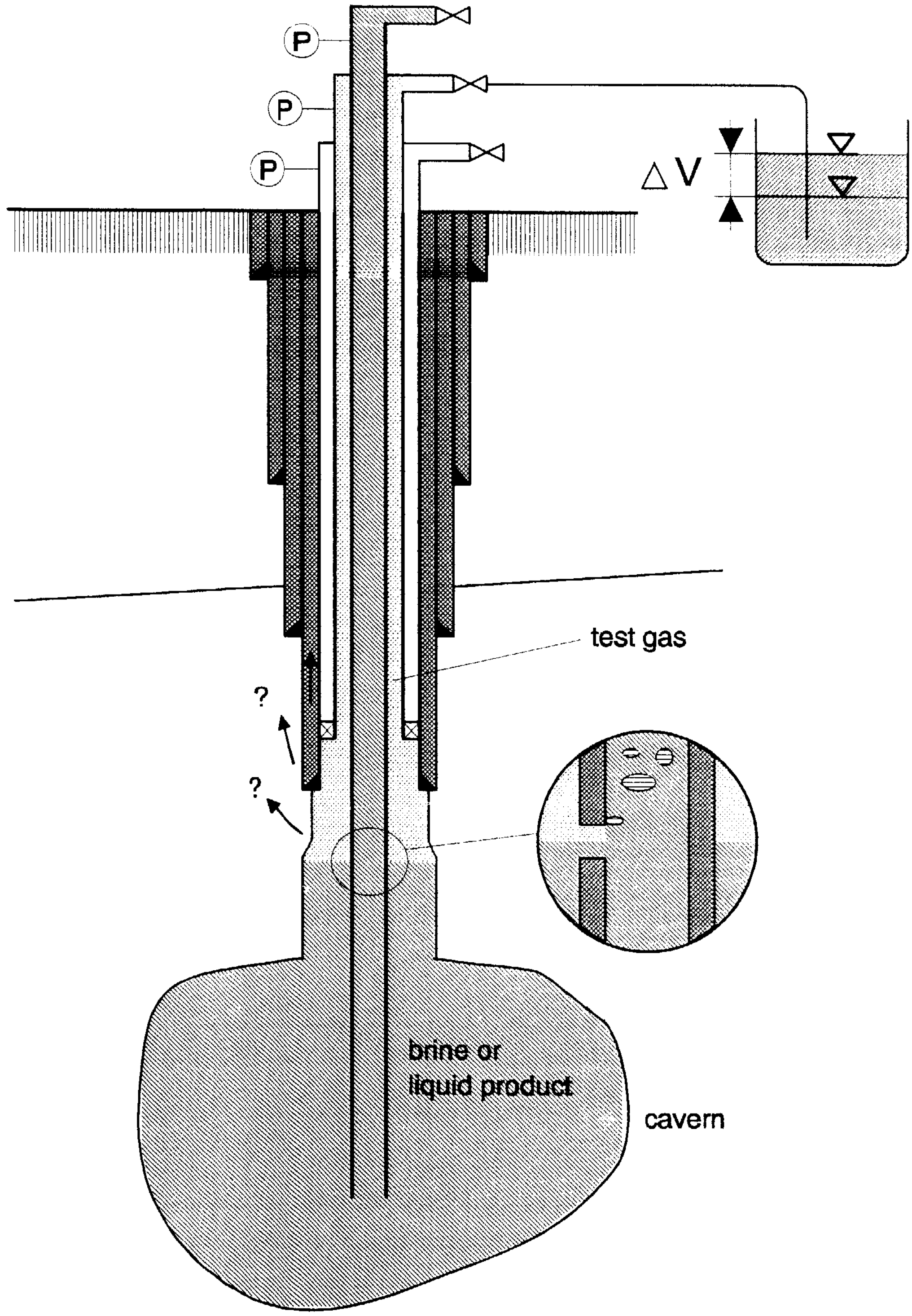
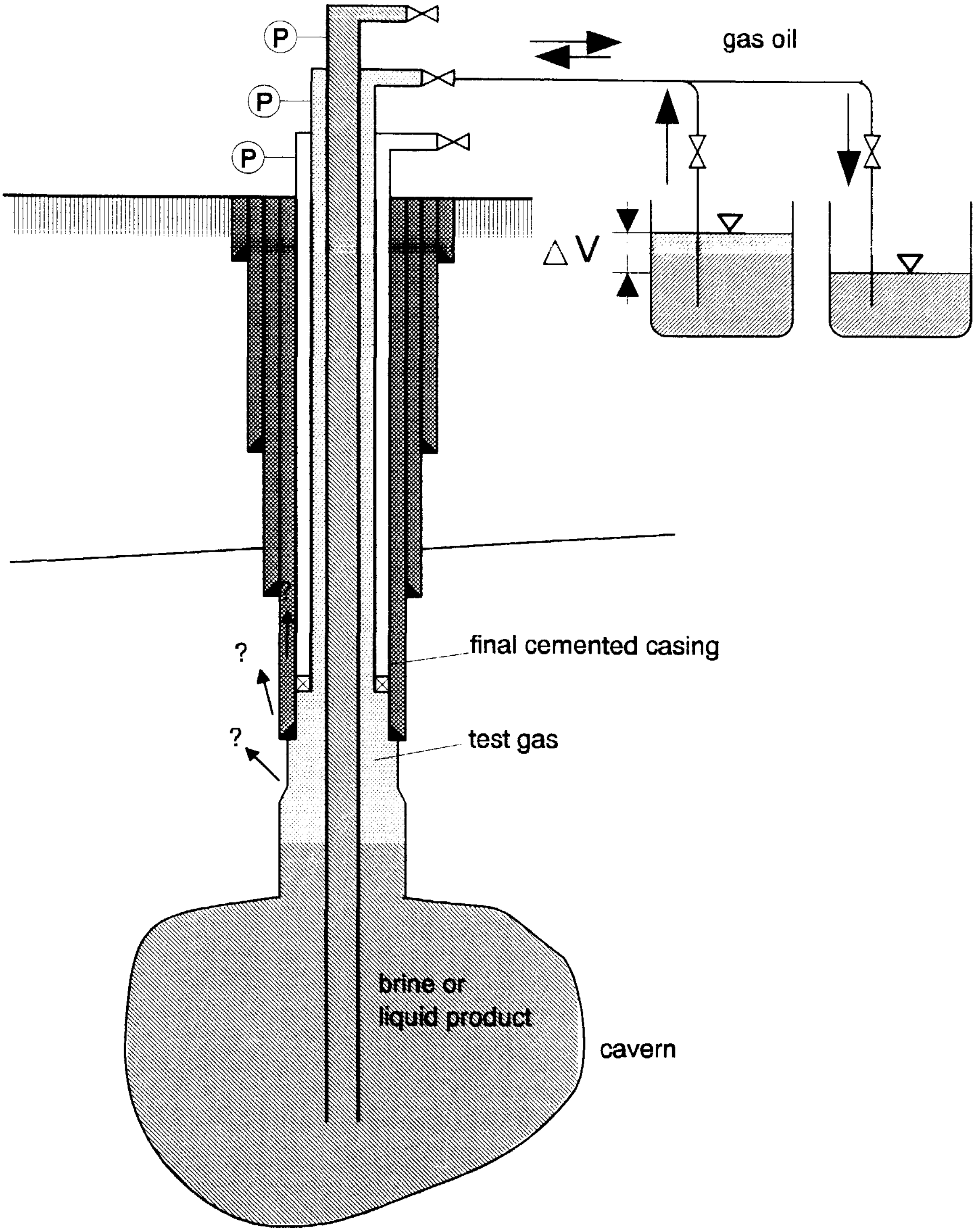
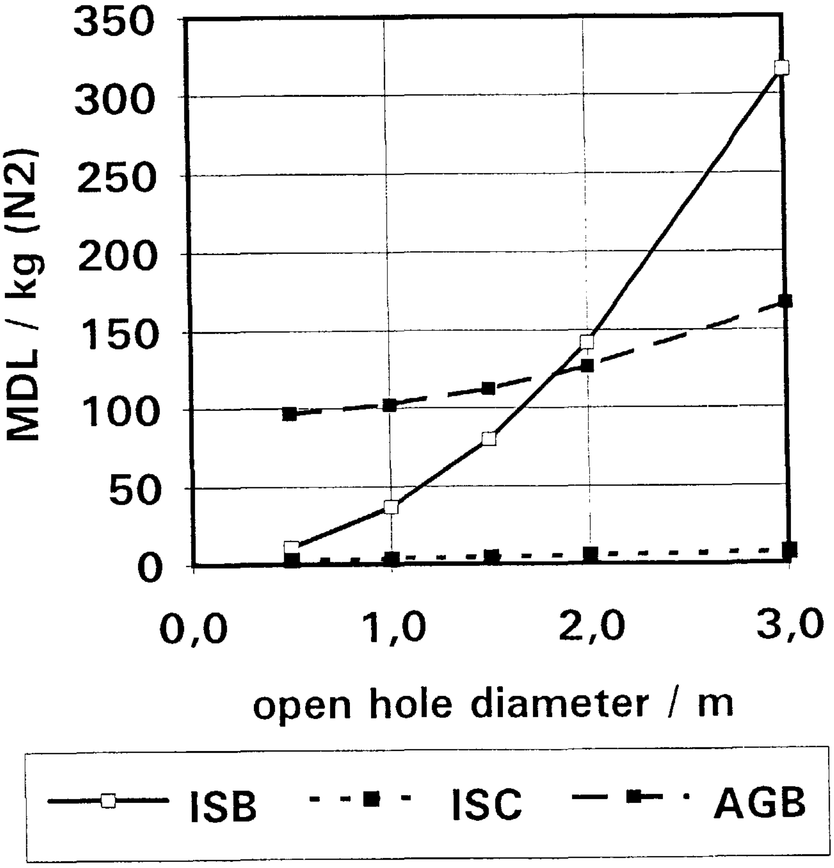


KBB	SMRI R&D project Reference for EWMIT	Fig. 3
444.2100	In-Situ Compensation Method (ISC Method)	Feb 95 Cro / OR



KBB	SMRI R&D project Reference for EWMIT	Fig. 4
444.2100	Above Ground Balance Method (AGB Method)	Feb 95 Cro / OR

Comparison of Minimum Detectable Leak Rate (MDL) for ISB, ISC and AGB Method



KBB	SMRI R&D project Reference for EWMIT	Fig. 5
444.2100	Comparison of MDL for ISB, ISC and AGB Method	Feb 95 Cro / OR