Shrinkage and Expansion in Oilwell Cements

API TECHNICAL REPORT 10TR2
FIRST EDITION, JULY 1997

American Petroleum Institute

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FOREWORD

Dimensional change after placement in oil and gas well cements, a phenomenon often referred to as shrinkage, has often been used to explain various problems (e.g., microannulus leading to bad cement bond logs, interzonal communication leading to costly remedial jobs and also lack of a seal to the gas of cement inflatable packers). Attempts have been made to find additives to decrease shrinkage, but it seems that shrinkage (as well as the exothermal reaction) are closely related to the hydration of the cement. The best solution for this shrinkage so far has been the identification of additives that favor the expansion of the cement. However, even if cement expands dimensionally, it still will shrink internally. In this case, the bulk expansion of the cement sample is simply superposed on an inner shrinkage that will affect the porosity of the sample. Shrinkage is not just one property of cement, such as rheology or thickening time that can be defined by one measurement. This is probably why little consensus has been reached today in the industry on this important issue, in spite of a large amount of work devoted to the subject.

In 1994, API proposed to open a work group on shrinkage. This report is an attempt to bring more understanding to this important area of cementing. One of the objectives of the work group was also to propose equipment to investigate shrinkage and expansion in oilwell cements. This report will address the objectives of that task group, which were:

- To develop standardized test procedures to measure expansion/shrinkage.
- To investigate possible impacts on invasion of wellbore fluids (gas, water).
- To standardize definitions of terms for cement hydration.

This report is a summary of all the background information and actual data that were generated to meet the objectives outlined above.

The equipment described in the report is the minimum recommended to measure the parameters in question.

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1 Introduction

A flawless cementation of the casing strings is fundamental not only for safety reasons, but also to keep drilling and production costs at a minimum level.

A cement job has to fulfill multiple conditions, but its main function is to prevent fluid and gas flow through the annulus by ensuring an impermeable bond and exhibiting sufficient compressive and shear bond strength.

Various factors can affect the sealing, such as poor mud removal, as well as bad slurry properties and borehole conditions. It is also recognized that the volumetric changes of cement during hydration substantially contribute to these problems. Bulk and inner volume changes produce bonding and permeability changes, respectively.

In this work, volume changes were better understood by measuring them on different slurries. Three different setups that correspond to three different testing conditions were used.

2 References

A list of suggested references may be found in Appendix A.

3 Definitions and Symbols

3.1 DEFINITIONS

For the purposes of this report, the following definitions apply:

3.1.1 cement: when the word is used alone, it refers to the material in any of the states from cement slurry to hard cement.

3.1.2 cement slurry: a mixture of Portland cement, water, and additives at a consistency below 50 Bc.

3.1.3 gel cement: cement slurry between the time at 50 Bc and the time at which the transit time of ultrasonic compressional P waves starts to decrease (UCA equipment).

3.1.4 gel cement under plastic state: a gel cement that can still deform to match the shape of its container.

3.1.5 hard cement: a material where the transit time of ultrasonic compressional P waves has decreased compared to the initial base line.

3.1.6 Portland cement: the powder as received from the supplier.

3.2 LIST OF SYMBOLS

The following symbols are used in this report:

V_i = initial volume of cement
V_f = final volume of cement
T = temperature of the cement
P = pore pressure inside the cement
M_t = micrometer measurement after curing
M_i = initial micrometer measurement
$\%Lex$ = defined by equation [1], linear expansion measured with the annular ring
V_i = initial volume of the sleeve
V_f = final volume of the sleeve
$\%Bex$ = defined by equation [3], bulk expansion measured with the sleeve
D_i = 1.65 inches (initial diameter of the sleeve)
D_f = final diameter of the sleeve
C_i = initial circumference of the sleeve
C_f = final circumference of the sleeve
h = height of the sleeve
ΔC_{12} = difference between C_{12} final and C_{12} initial
$\%Bch$ = defined by equation [4], bulk volume change measured with the membrane
V_p = volume compensated by the piston movement
V_g = volume of gas entered in the slurry
V_i = 392.5 cm^3 (estimated by filling up the cell with water)
$\%Ish$ = defined by equation [5], inner shrinkage measured with the CHA

4 Discussion of Shrinkage and Expansion

4.1 CAUSE AND RESULTS OF SHRINKAGE AND EXPANSION

Shrinkage and expansion in cement result from the formation of hydration products having a different density from the compounded density of the reaction components. This can result in:

a. Change in pore volume.
b. Change in pore pressure.
c. Change in sample dimensions.
d. Change in internal stress.

The change in sample dimensions will be referred to as bulk shrinkage or bulk expansion. The change in pore volume will be referred to as inner shrinkage.

Shrinkage and expansion of cement refer to the result of the measurement of a volume change in cement. This will be expressed in percent by volume. The volume to which all volume changes are related, is the volume of the slurry immediately after mixing and placement in the experimental equipment. The general expression for shrinkage and expansion is: