A SIMPLE CHECK FOR THE PRESENCE OF SOLID SALT IN THE PORE SPACE OF GAS RESERVOIRS BY COMPARING POROSITY AND GRAIN DENSITY CHANGES RESULTING FROM SALT EXTRACTION

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Abstract The measurement of petrophysical properties on uncleaned, oven-dried plugs followed by a second measurement after salt extraction is a common practice in the evaluation of North German gas reservoirs. The calculated density of the extracted material allows a check for solid salt if porosity and grain density are accurately determined. The presence of naturally occuring solid salt in the reservoir is indicated by a porosity change greater than 15 % by volume and an average density of the extracted material close to 2.16 g/cm^3.

The evidence of plugged pore throats due to the precipitation of salt during the drying process is also indicated. A core-graph computer program allows on a routine basis a check for solid salt and gives an indication whether it occurs naturally or originates either from drilling mud filtrate or formation water.

INTRODUCTION

In North Germany, where salt domes frequently occur in the the neighbourhood of oil and gas reservoirs, considerable problems are encountered in laboratory determination of porosities. The use of salt-saturated drilling muds and the presence of high salinity brines in the gas bearing middle Bunter, Zechstein, and Rotliegend formations often result in porosities and grain densities which are too low when measurements are carried out on uncleaned, oven-dried samples. The method described in in this paper allows a differentiation between solid salt occuring as an *in situ* formation component and solid salt as an artifact.

A change in the measured porosity from 5 % before salt extraction to 25 % after salt extraction in one gas reservoir was the reason for developing a systematic approach to detect solid salt in the pore space of core samples.

POROSITY AND GRAIN DENSITY DETERMINATION

Of the several procedures for measuring porosities described in the publication API RP-40 (1960) we decided to use the bouyancy method. This method is also called the Archimedes method.

Procedure

Drill core plugs, 3.0 cm in diameter by 4 cm length with fresh water (4 samples/meter). Dry the plugs in an oven at 105 °C for 24 hours. Determine the dry weight with a balance accurate to 10 milligrams. Place the weighed samples in a desiccator and apply a high vacuum for one hour. Saturate the samples with isopropanol (IPA) by drawing the liquid slowly into the evacuated vessel until the samples are completely submerged. Allow the plugs to saturate 24 hours by capillary forces (samples with gas permeabilities below 0.1 mD need 48 hours saturation time). Weigh the samples in a cradle submerged in IPA. Weigh the saturated samples after wiping them with a IPA-wet cloth. Check the density of the IPA for each batch of samples with a lucite plug of known density.

Calculations

The density of the IPA (ρ_{IPA}) is obtained from the dry weight (m_1) and the submerged weight (m_2) of the lucite plug:

$$\rho_{IPA} = 1.185(m_1 - m_2)/m_1 \ . \tag{1}$$

Where 1.185 g/cm^3 is the density of the lucite.

Effective porosity (ϕ) in % is calculated from the dry weight of the core plug (m_1), the submerged weight (m_2), and the saturated weight (m_3):

$$\phi = 100(m_1 - m_2)/(m_3 - m_2) \tag{2}$$

The grain density is determined using the equation

$$\rho_g = m_1 \rho_{IPA}(m_1 - m_2) \ . \qquad (3)$$

Precision

The repeatability (duplicate results by the same operator) for consolidated non-vuggy plugs is ±0.1 porosity units (p.u.) while the reproducibility (results submitted by two laboratories) is ±0.2 p.u. This is better than the ±0.5 p.u. which are acceptable according to RP-40.

Luffel and Howard (1988) were only able to achieve a reproducibility of ±0.25 p.u. by applying strict quality control and making reruns for non-Archimedean methods.

SOLID SALT IN THE PORE SPACE OF GAS RESERVOIRS

The absence of oil and condensate in most of the North German gas reservoirs allows the measurement of first (quick shot) petrophysical data on uncleaned oven-dried samples. In most cases a second measurement of porosity, gas permeability, and grain density after a salt extraction, a process which takes approximately two weeks, delivers more reliable results.

General

The occurance of solid salt in the pore space of gas reservoirs was first detected by Rieckmann (1965) using wet chemistry methods. Figure 1 shows the porosity, permeability and grain density change due to salt extraction and Table 1 is a listing of the petrophysical data for the first 26 samples of a core cut from a North German middle Bunter formation. The abnormal behaviour of the samples was so obvious that further investigations were necessary. These showed convincingly the presence of sodium chloride in the pore space.

The installation of a series of computer programs for collection, reporting, and plotting of petrophysical data provided the opportunity to check the data for abnormal values and contradictions on a routine basis. One special test indicates the presence of solid salt. The average density (ρ_{SALT}) of the material which is removed during salt extraction is calculated from the equation:

$$\rho_{SALT} = \frac{\rho_1(100 - \phi_1) - \rho_2(100 - \phi_2)}{\phi_2 - \phi_1} \qquad (4)$$

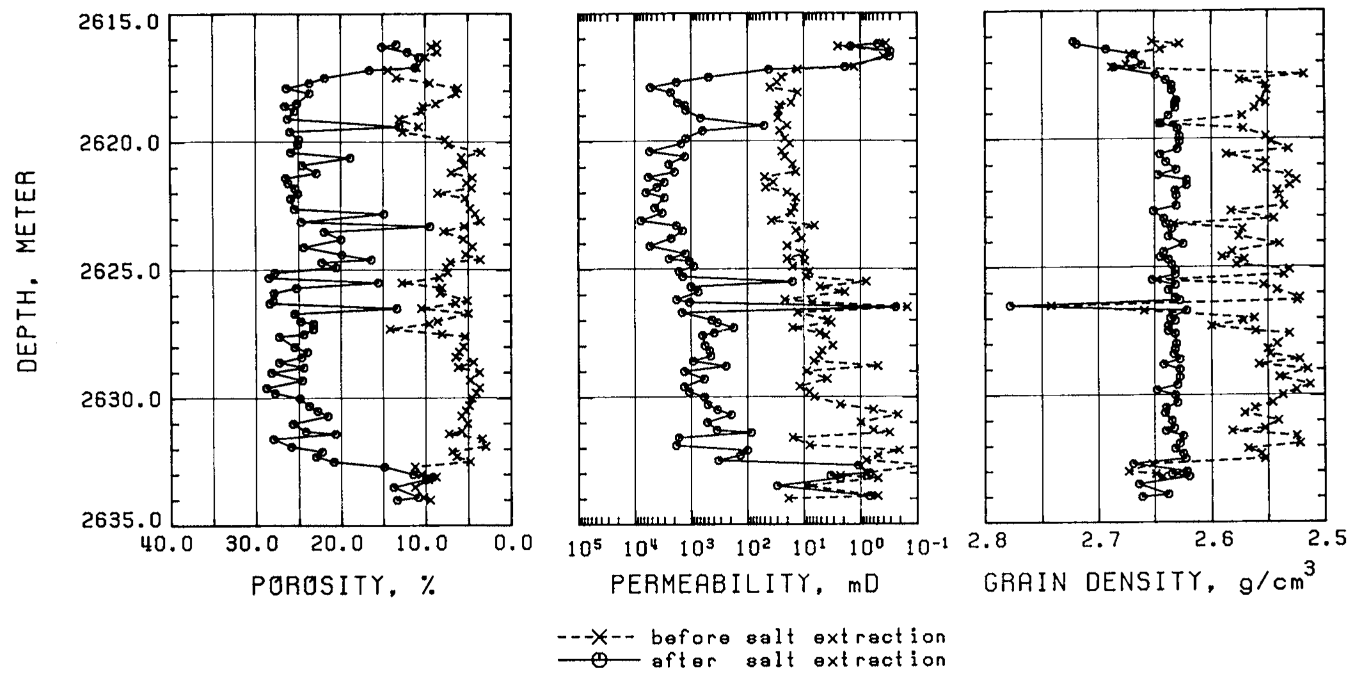

FIGURE 1 Core-graph. Alteration of petrophysical data due to salt extraction.

TABLE 1 Petrophysical data for the first 26 samples of Figure 1.

POROSITY, GAS PERMEABILTY, AND GRAIN DENSITY

		BEFORE SALT EXTRACTION			AFTER SALT EXTRACTION		
SAMPLE #	DEPTH m	POROS %	PERMEABILITY mD	DICHTE g/cm3	POROS %	PERMEABILITY mD	DICHTE g/cm3
35450	2616.2	8.6	0.3600	2.652	13.4	0.5000	2.722
35451	2616.3	9.3	2.5000	2.628	15.1	1.5000	2.719
35452	2616.5	8.6	0.3300	2.645	12.1	0.3000	2.693
35453	2616.7	10.0	0.4000	2.672	10.8	0.3100	2.668
35454	2617.1	11.0	1.3000	2.675	11.2	1.9000	2.661
35455	2617.2	14.4	13.0000	2.688	16.6	42.0000	2.686
35456	2617.5	13.4	25.0000	2.518	21.9	490.0000	2.649
35457	2617.7	9.5	30.0000	2.575	23.7	1830.0000	2.640
35458	2617.9	6.2	40.0000	2.552	26.4	5280.0000	2.635
35459	2618.1	6.4	13.0000	2.551	23.7	2310.0000	2.635
35460	2618.5	8.8	17.0000	2.557	25.2	1740.0000	2.631
35461	2618.6	10.3	27.0000	2.552	26.6	1310.0000	2.632
35462	2618.8	10.5	28.0000	2.562	25.5	1250.0000	2.632
35463	2619.1	13.1	29.0000	2.573	26.3	680.0000	2.638
35464	2619.4	10.8	20.0000	2.645	13.1	51.0000	2.645
35465	2619.6	12.7	27.0000	2.572	26.0	630.0000	2.630
35466	2619.9	7.7	22.0000	2.552	25.0	1240.0000	2.628
35467	2620.1	7.3	18.0000	2.547	25.1	1500.0000	2.628
35468	2620.4	3.5	25.0000	2.532	25.9	5500.0000	2.630
35469	2620.6	5.8	22.0000	2.587	18.9	1300.0000	2.645
35470	2620.9	5.5	16.0000	2.552	24.6	2500.0000	2.640
35471	2621.2	7.0	14.0000	2.560	22.9	1990.0000	2.631
35472	2621.4	4.5	50.0000	2.532	26.5	5810.0000	2.647
35473	2621.6	5.2	35.0000	2.525	26.2	3010.0000	2.622
35474	2621.8	4.6	48.0000	2.531	25.4	4080.0000	2.622
35475	2622.0	8.6	20.0000	2.542	25.1	6370.0000	2.632

As previously ϕ is the porosity in % and ρ is the grain density in g/cm^3. Subscript 1 refers to data before salt extraction and subscript 2 to data after salt extraction.

$\Delta\phi_{ds}$ which is the porosity increase caused by precipitation of salt during the drying process is calculated in the next step

$$\Delta\phi_{ds} = 0.15\ \phi_2 \tag{5}$$

where 0.15 is the evaporation residue in fraction by volume of a saturated sodium chloride solution.

Finally, the so-called excess porosity increase $\Delta\phi_{exc}$, which cannot be explained solely by salt precipitation is given by equation (6):

$$\Delta\phi_{exc} = \Delta\phi_{ds} - (\phi_2 - \phi_1). \qquad (6)$$

These calculations enable three types of interpretation, listed below in Table 2, to be established:

TABLE 2 Interpretation of calculation results.

Type	Calculation result	Interpretation
1	$\Delta\phi_{exc} \geq 0$	No solid salt is present. If ρ_{SALT} is close to 2.16 g/cm^3 the porosity increase is caused by salt precipitation from brine or drilling mud filtrate. If ρ_{SALT} is close to 0 g/cm^3 then the porosity increase is caused by dissolution of plugged pore throats .
2	$\Delta\phi_{exc} \leq 0$ **and** $\rho_{SALT} = 2.16 \pm 0.2$	The presence of solid salt in the pore space of the reservoir should be assumed.
3	$\Delta\phi_{exc} \leq 0$ **and** $0 < \rho SALT < 1.9$	The porosity increase is probably caused by dissolving salt from plugged pore throats.

Testing the solid salt conception

The data from Table 1 were used to confirm the presence of solid salt by calculation instead of tedious wet chemistry. Table 3 contains the quantities described in the previous text for the 26 samples of Table 1.

Most of the samples meet the "Type 2" criteria (see Table 2) without any restriction. Limitations must be made if the porosity change is less than 2 p.u., and below a porosity change of 0.3 p.u. an interpretation is almost impossible. Table 4 shows the maximum variation of ρ_{SALT} caused by a

TABLE 3 Indications for solid salt

SAMPLE #	$\Delta\phi$ %	$\Delta\phi_{ds}$ %	$\Delta\phi_{exc}$ %	ρ_{SALT} g/cm³
35450	4.80	2.01	-2.79	1.389
35451	5.80	2.26	-3.54	1.296
35452	3.50	1.81	-1.69	1.440
35453	0.80	1.62	0.82	3.118
35454	0.20	1.68	1.48	8.891
35455	2.20	2.49	0.29	2.764
35456	8.50	3.28	-5.21	1.314
35457	14.20	3.55	-10.64	2.226
35458	20.20	3.96	-16.24	2.250
35459	17.30	3.55	-13.74	2.181
35460	16.40	3.78	-12.62	2.219
35461	16.30	3.99	-12.31	2.192
35462	15.00	3.82	-11.18	2.214
35463	13.20	3.94	-9.25	2.210
35464	2.30	1.96	-0.34	2.645
35465	13.30	3.90	-9.40	2.249
35466	17.30	3.75	-13.55	2.223
35467	17.80	3.76	-14.03	2.206
35468	22.40	3.88	-18.51	2.208
35469	13.10	2.83	-10.26	2.228
35470	19.10	3.69	-15.41	2.205
35471	15.90	3.43	-12.46	2.216
35472	22.00	3.97	-18.02	2.148
35473	21.00	3.93	-17.07	2.184
35474	20.80	3.81	-16.99	2.205
35475	16.50	3.76	-12.73	2.133

weighing error of 10 milligrams in each of the three weights needed for a porosity determination.

After installing a software extension to our core-graph computer program all available data were checked for indications of solid salt. The investigation showed that 15 wells out of 200 probably contain solid salt. Only five of the original core reports noted the presence of solid salt in the reservoir. Solid salt has only been found in the middle Bunter and Zechstein formations. In one case solid salt in the pore space was shown to be the explanation for a permeability barrier which had been deduced by geologists from the production behaviour of the wells.

TABLE 4 **Maximum error for ρ_{SALT} caused by a weighing error of ±10 mg**

$\Delta\phi$ p.u.	ρ_{SALT} g/cm^3
5.0	±0.10
4.0	±0.12
3.0	±0.17
2.0	±0.26
1.0	±0.59
0.7	±0.94
0.5	±1.54
0.4	±2.27
0.3	±4.35
0.2	±47.9

RECOMMENDATIONS

If *in situ* solid salt is indicated by the calculation method, then another set of plugs should be drilled using a light mineral oil which can be extracted with chloroform. Tests showed that leaching by fresh water during plug drilling alters the plug porosity from 5.0 % (drilled with oil) to 5.5 to 6.0 % (drilled with fresh water) while the grain density changes from 2.55 g/cm^3 to 2.56 g/cm^3. These changes might appear to be tolerable, but the resultant change in gas permeability from 40 mD to 400 mD is inacceptable.

If the productivity of a well is much less than calculated from the laboratory data after the applying appropiate corrections for slippage, compaction and relative permeability, the presence of solid salt in the reservoir should be considered. Even older cores might be used to confirm this suspicion.

Information about the presence of solid salt also avoids overestimation of reservoir volumes.

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