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Dielectric and radio-frequency emission parameters of formation and condensate waters from gas wells

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Abstract

A comprehensive study of water samples from the Medvezh'e, Yubileinoe, and Yamsoveiskoe oil-gas condensate fields was performed for the rapid identification of liquids from gas wells. The proportions of condensate, formation, and process waters in the produced mixture were assumed on the basis of their physicochemical parameters and chemical composition. Their dielectric parameters were studied at a frequency of 0.6 GHz. Dependences of the dielectric and radio emission parameters on the total salinity and concentrations of major cations have been established. Algorithms for identifying different types of well water based on their dielectric parameters are proposed.
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Introduction

Increasing the productivity of gas and gas-condensate wells is an important task relevant to the improved development of gas fields. The relative gas recovery from reservoirs for existing methods of development ranges from 50 to 90%. The problem of gas recovery enhancement is particularly urgent for the late stage of development of gas and gas condensate wells, where the rapid inflow and accumulation of formation water in the bottom-hole area can lead to blocking of the producing formation and production go-off. For this reason, there are an increasing number of idle wells in the Cenomanian deposits of the Far North. Maintaining a predetermined flow rate of gas and gas condensate largely depends on the influx of formation (primarily bottom) water into wells. Gas-well streams always contain liquid, which may vary in composition depending on the stage and conditions of operation.

There are three main types of liquids produced with gas from wells (Methodological Guidance, 2005):

1) Ultrafresh condensate water (salinity up to 1 g/dm^3) formed as the gas moves from the formation to the wellhead with a change in thermobaric conditions;

2) formation (bottom) water varying widely in salinity and composition;

3) process fluids pumped into wells to enhance the production and during repairs. These include: calcium chloride (solution), methanol, diethylene glycol, inhibitors of corrosion and salt formation, drilling fluids, products of hydrochloric acid treatment, surfactants, etc.

In the absence of complications in well operation, the produced liquid is usually condensate water. After well workover, the well production stream contains a sharply increased content of the process fluid consisting of residuals of the solutions used in the workover. Over time, its content should decrease during normal well operation. The appearance of bottom water in the gas stream indicates possible water flooding. This process can develop rapidly and is accompanied by intense destruction of the bottom-hole zone and a sharp increase in the liquid and sand contents, which presents a hazard to the operation of wellhead and process equipment. Determining the composition of well liquids is one of the most

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important components in the overall system of control over the development of gas fields.

Currently, the laboratory diagnostics of liquids is performed by chemical analysis of samples taken at the wellhead. In the technique developed at the Institute of Problems of Oil and Gas of RAS (IPNG RAS) taking into account the salinity and ionic composition of dissolved salts in liquids, the determination of the genesis of samples includes two steps. In the first step, a diagnostic group in terms of the total salinity is determined. In the second step, the type of the sample is identified according to the sodium-chloride genetic coefficient (rNa/rCl) or the proportion of each type of liquids is determined. The main drawback of this approach is the lack of speed, which is of particular importance.

This paper presents the results of development of radiophysical methods for rapid diagnostics of liquids based on the measurement of dielectric and radio emission parameters.

The physical basis for the differentiation of various types of liquids produced from wells are established dependences of the dielectric characteristics of saline waters on temperature, mass concentration, and type of dissolved salts (Klein and Swift, 1977; Romanov, 2004; Stogrin, 1971). In this case, the temperature was constant.

It is common to describe the complex dielectric constant (CDC) of aqueous salt solutions at different frequencies using the Debye model of dielectric dispersion and ionic conductivity. The effect of the salt concentration (S) is taken into account by constructing approximation dependences for the parameters included in the model: the static dielectric constant $\varepsilon_s(t, S)$ and the relaxation time $\tau(t, S)$ (Mitnik, 1978; Sadovskii et al., 2013; Sharkov, 2014).

The effect of S on the CDC of a solution, most pronounced in the ultra-high-frequency range of electromagnetic waves, including the selected frequency of 0.6 GHz, manifests itself differently for the real ε' and imaginary ε'' parts of the CDC. For small S, the dependence $\varepsilon'(S)$ shows a sharp decrease in ε'. This is due to the dielectric saturation of water molecules in the near hydrate shells of cations and anions and their exclusion from the formation of the effective dipole moment. Unlike ε', the value of ε'' increases nonlinearly with increasing S, which is explained by an increase in the ionic conductivity of the solution (Lileev et al., 1992; Lyashchenko et al. 1993).

There are various regions of application of the dielectric constant:

1. Simultaneous measurement of the volume, CDC, and density of condensate water makes it possible to evaluate the properties of multiphase flows in the gas condensate (May et al., 2004).

2. The CDCs of core samples of sediments selected from seabed oil and gas regions contain information on the presence of gas hydrates, oil, and authigenic carbonates (Francisca et al., 2005).

3. For sandy-clayey samples saturated with salt solution-diesel emulsions containing not more than 10% salt solution, the CDCs measured in the frequency range from 10 MHz to 1 GHz at temperatures of 25–65 °C depend weakly on the

mineral composition of the sample and emulsion concentration (Bobrov et al., 2015).

4. On this basis, the CDCs of water-oil emulsions with a specified volumetric water content have been determined. The obtained dependences of the CDC of emulsions on the volumetric moisture content have been described using asymmetric formulas for a mixture of polar and nonpolar liquids (Krotikov et al., 2015).

5. The CDCs of bentonite-oil-salt solution mixtures with different water and oil saturation have been studied experimentally in the range from 10 kHz to 4 GHz at temperatures of 25–60 °C. It has been found that in addition to the Debye relaxation region of water, this frequency range contains two more relaxation regions due the interfacial interaction between the components of the mixture. A spectroscopic model taking into account multi-frequency relaxation has been proposed to describe the CDC and the equivalent electrical conductivity of mixtures. The dependence of the model parameters on the water saturation and temperature of samples has been derived (Epov et al., 2011).

In this study, the dielectric and radio emission characteristics of formation, process, and condensate waters produced from gas wells were investigated at a frequency of 0.6 GHz. Their microwave diagnostics was based on the dependences of the dielectric characteristics of water on the temperature, mass concentration, and ionic composition of dissolved salts.

Method of research

We studied 20 liquid samples of mixtures of condensate, formation, and process waters from gas wells in the Yubileinoe, Yamsoveiskoe, and Medvezh'e fields.

Hydrochemical characteristics

In all samples, we measured pH values and conductivity, and the concentrations of chlorides (Cl^-) and cations (Mg^{2+}, Ca^{2+}, Na^+, K^+).

pH values were determined using a HI 9125 (HANNA Instruments) portable pH meter. Before each pH measurement, the instrument was calibrated using reference solutions with known pH values (3.56, 4.01, 6.86, 9.18). The measurement accuracy is ±0.01 pH.

Electrical conductivity in the samples was determined using a Cond315i (Wissenschaftlich-Technische Werkstätten GmbH) portable conductivity meter. The device measures the electrical conductivity in the range from 0.0 mS/cm to 500 mS/cm with a relative error of ±0.5%.

Chloride ions content was measured by a potentiometric method using an EXPERT 001-3.0.4 (Ekonix-Expert) portable ion meter with an ELIT-261Cl ion-selective electrode. The range of measured concentrations is from 0.4 to 3550 mg/dm^3. The relative error in the range of concentrations from 10 to 500 mg/dm^3 is 10%.