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Experimental modeling of abandoned shallow oil wells convergence

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A B S T R A C T

The paper discusses issues related to inappropriately abandoned production wells in depleted oil field near Hodonín (South Moravia, Czech Republic). The characteristic effects of the well deformation, depending on whether there was a possibility of fluid displacement from the well space were defined on the basis of model experiments. It was proven that in the analyzed conditions, convergence of abandoned wells is not equivalent to their proper liquidation, because the communication of media is still possible, creating a risk of pollution of groundwater and land surface.

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1. Introduction

The Hodonín oil field under consideration is located in the northern part of the Lower Moravian depression (northern part of the Vienna Basin) along the right bank of the Morava River, about 5.5 km south-west from the town of Hodonín. The oilfield consists of several elevated structures, with related accumulations of hydrocarbons. They can be treated as separate deposits, which are part of the so-called Hodonín-Gbel play. The productive series is represented by Sarmatian sandy marls with inserts sand oil horizons, as well as sandstone and lignite beds. Below lie the sandy marls classified as upper Badenian. The overburden consists of sandy marls, clays and sands of Sarmatian age, covered by Quaternary clayey-sandy sediments of fluvial terraces of the Morava River — Fig. 1.

The first oil wells in this area were drilled in 1919. They were localized on the basis of the observed leakage of gas and oil in the old riverbed of Moravia. Signs of oil were found at a depth of 218 m below the surface. Since the start of operation in the twenties of XX century, hundreds of production wells have been drilled in the Hodonín region. These wells, gradually excluded from the operation, were systematically plugged, although often after a long time since the abandonment. The plugging technology was often very primitive (removal of casing, filling with clay or soil), or incorrectly performed. Many of the wells were left without plugging. In some oil fields, particularly where the reservoir water have extensive coverage, a gradual pressure buildup may occur (MND Group, archival data). This process can lead to restoration of spontaneous connections between the shallow productive layer (situated 100 to 180 m below the surface) and the overburden (surface), through the space of poorly plugged well. Example effects of improper well abandonment are shown in Fig. 2.

In order to study the phenomena responsible for the passage of fluids through abandoned wells and mechanisms of well space deformation in Sarmatian sediments, a program of simple model experiments was designed. The purpose of these models was to provide the view of underground processes occurring after the casing removal in order to abandon oil well in terms of exceeding the rock failure criterion after the thereby induced stress deviation. It should be underlined, that time dependent effects such as creep were beyond the study extent and model resolution.

2. Shallow well convergence and its effects

Interactions between rock mass and the space within the abandoned borehole can be considered in two possible scenarios:

A) cemented or partly cemented sections of casing were left in the borehole,
B) the borehole is open and filled with mud or reservoir fluid.

According to the scenario A the destruction of casing due to external pressure is unlikely at least to a depth of several hundred meters (Barree and Mukherjee, 1996; Shuling et al., 2010, 2012). Already at the stage of well design calculations are carried out to prevent the casing destruction due to external or internal pressure. Casing shall be conducted on the basis of these calculations and empirical experience as well. Improperly liquidated production well however, may enable communication between the collector and the surface or zones of lower reservoir pressures. Communication can take place inside the well, or outside the casing, in

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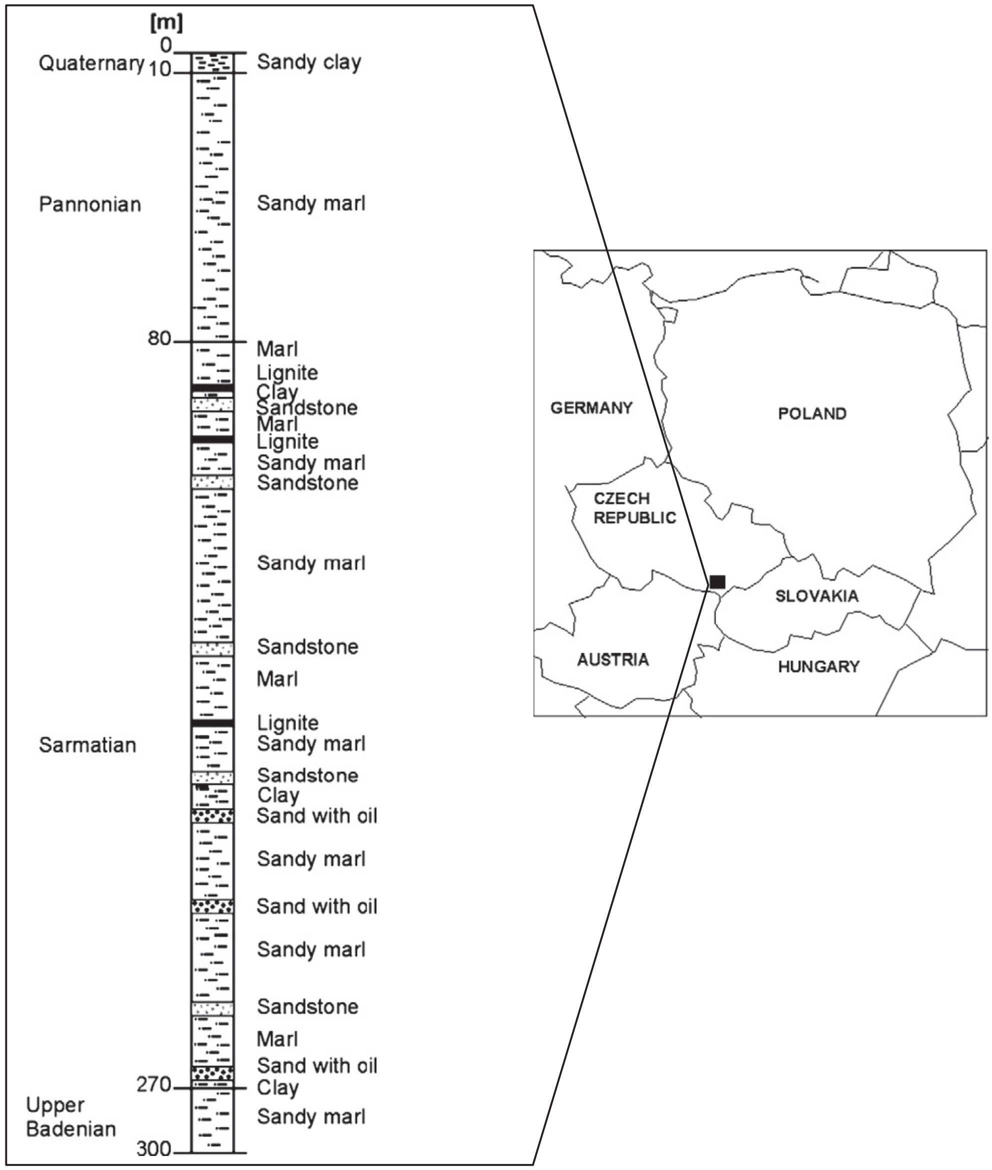

Fig. 1. Litostratigraphic profile of the Hodonín oil field and its location.

case of incorrect cementing (Peng and Zhang, 2007; Robello and Xiushan, 2009; Aadnoy and Looyeh, 2011).

Under the scenario B, the well is filled with mud or reservoir fluid. Assuming the pressure exerted by the liquid column in the well — p_s equal to hydrostatic pressure — p_h, and the lithostatic pressure — p_{bg}, the pressure distribution in simplified is in general the following:

1. $p_s < p_{bg}$; deformation and convergence of the well occur, the initial circular cross-section of the well is transformed into an elliptical or pear-shaped, depending on the anisotropy of the rock.
2. $p_s = p_{bg}$; there is no deformation, the system is in equilibrium.
3. $p_s > p_{bg}$; such conditions may occur in the case of collector layers of anomalous (lower than hydrostatic) pressure, or in the case, when the high pressures from other penetrated horizons are transmitted by the fluid in the well space.

This implies that in a complex geohydrodynamical system, part of which is the well space, the transition between the states of pressure distributions is possible (especially when it comes to reservoir pressure buildup), which should be considered in the context of time (Aldorf and Exner, 1986).

In earlier drilling practice the concept of so-called "critical depth" – a borrowing from underground mining – has been used uncritically, e.g. Kastner, 1962: "at a certain depth, each rock has latent plastic behavior, what means that it is in a state in which the cohesion of individual particles of the rock can no longer be determined, and the transition from brittle to plastic state occurs". According to Kastner (1962) and other authors (e.g. Salustowicz, 1965; Voropinov and Kittrich, 1966) this is possible, if the stress caused by the overburden is greater than the compressive strength of rocks. It should therefore be expected that with increasing depth the stress field will change, and will cause a decrease of strength of the rocks. Such an approach is presented in the work of Kvapil (1957), where an empirical formula describing the critical depth (H_k)is given:

$$H_k = \frac{3p \ \varphi \sin\varphi}{2\gamma \cos\varphi \ 9,81} \tag{1}$$

where:

H_k critical depth,

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