Analysis of the Relationship Between Thermal and Baric Subsurface Conditions in the Northern Part of the West Siberian Plate

P Gorbunov

Tyumen Industrial University, 38, Volodarskogo st., Tyumen, 625000, Russia

E-mail: razpas@mail.ru

Abstract. Reservoir pressures and temperatures are the most important parameters that characterize the energy state of reservoir systems. They determine the amount of hydrocarbons that are contained in the bowels of the earth, as well as the operating modes of the deposits. The values of reservoir pressures and temperatures have a direct impact on the safety of drilling wells. It is known that within the interior of the northern part of Western Siberia there is one of the most harsh thermobaric regimes. The researchers recorded numerous manifestations of abnormally high reservoir pressures and high reservoir temperatures. In this article, the author sets the task of detailing the regularities of changes in reservoir temperatures and pressures in the interior of the study area. The second task is to find the relationship between these parameters and explain its nature. The results of the research should be aimed at improving the safety of exploratory drilling, and can also be used in oil and gas exploration.

1. Introduction

The thermobaric regime is one of the most important characteristics of the earth's interior and is composed of two components - reservoir pressures and reservoir temperatures.

Reservoir temperature is a reservoir parameter that characterizes its thermal state. Formation temperatures are formed under the influence of heat flow directed to the surface from the deep zones of the Earth [1]. The main mechanism for the redistribution of heat in the earth's crust is conductive heat transfer, due to the thermal conductivity of the rocks. The second part of the process is a convective transfer associated with the movement of fluids in a void space (pores, caverns, cracks) of rocks. The parameters of the temperature situation in the Earth Crust are the geothermal gradient (increase in reservoir temperature per 1 m of depth) and the geothermal degree (the value inverse to the geothermal gradient) [2, 3].

The reservoir temperature depends on the depth and geotemperature features of the corresponding section of the earth's crust. Within the upper part of the earth's crust, the change in reservoir temperature with depth occurs naturally, often linear.

Reservoir pressure is a pressure of a liquid or gas and their mixtures in the communicating pores of a rock [4].

Reservoir pressure is a parameter that characterizes the energy of oil and gas (water) bearing complexes. In formation of reservoir pressure participate hydrostatic pressure, Archimedean force, pressure resulting from changes of reservoir volume and expansion (or compression) of fluids. There
are initial (before the development of the underground reservoir) and the current reservoir pressure [5,6].

In comparison with hydrostatic pressure, reservoir pressures are divided into normal and anomalous. The first one are directly dependent on the depth of the formation, i.e. the pressure increases every 10 m by 0.1 MPa. Reservoir pressures that are substantially higher than hydrostatic pressures are called abnormally high reservoir pressures (AHRP).

According to the adopted classification, the AHRP is reservoir pressure that is 1.3 times higher than the hydrostatic pressure, i.e. the coefficient of anomaly $K_a$, (exceeding of the reservoir pressure over the hydrostatic pressure) is 1.3 [7].

AHRP are formed in isolated reservoir systems. There is no consensus about the genesis of abnormal reservoir pressure. According to some researchers, the most important part in AHRP origin is the temperature factor because the coefficient of thermal expansion of fluids enclosed in an isolated volume of rocks is significantly greater than that of the mineral components of rocks. AHRP are observed at depths of 3-4 km. Usually AHRP exceed hydrostatic pressure by 1.3-1.8 times, considerably less often - in 2.0-2.2 times [8].

2. Obtained data and analysis

According to many researchers [9, 10, 11, 12, 13, 14] reservoir pressures and temperatures within the northern part of Western Siberia have a complex distribution pattern. To confirm this thesis, the author studied and systematized a large volume of the results of thermometric and hydrodynamic studies conducted in exploration wells drilled within the northern part of Western Siberia.

As a result, author gathered a database containing 1530 measurements of reservoir pressures and 1971 measurements of reservoir temperatures (Figure 1). The results of the research cover all the identified productive complexes, beginning from the Upper Cretaceous (Turonian stage), ending with the lower Jurassic (the Hettingian stage).

![Figure 1. Graphs of changes in reservoir pressures (a) and reservoir temperatures (b) with depth.](image)

Using the collected material, and also taking into account the tectonic structure of the territory and the features of oil and gas zoning [15, 16, 17, 18, 19], the author performed a unique zonation of the study area according to the features of changes in reservoir pressures and temperatures with depth. Within the territory of the north of Western Siberia author identified 33 zones with unique laws of reservoir pressure changes with depth and 28 zones with unique laws of reservoir temperature changes with depth (Figure 2).

For reservoir pressures, it was found that in the upper, Aptian-Albian-Cenomanian part of the sedimentary cover, the reservoir pressures correspond to hydrostatic pressures. In the lower Neocomian and Jurassic parts of the section, the manifestation of the AHRP is recorded. Therefore,
the change in reservoir pressures with depth is described by two functions. One for the upper part of the sedimentary cover and the second for the lower part where the AHRP is observed.

It was established that the anomaly coefficient value of the AHRP in the Jurassic and Neocomian deposits within the study area increases from the south (from 1.3) to the north (to 2.2). The largest measured values of reservoir pressures were recorded in the north of the Yamal Peninsula. Within the zones 1, 2, and 3 in the Jurassic strata, the anomaly coefficient value of reservoir pressures graduates from 1.7 (layer J2) to 2.3 (layer J3).

Reservoir temperature, as already mentioned, increase with depth. The changes in reservoir temperatures with depth, as can be seen from Figure. 1 (b), can be approximated by a linear function. Within each of the 28 temperature zones identified by the author, the change in the reservoir temperature with depth is describe by its unique linear function. The geothermal gradient calculated with established regularities within the northern part of West Siberia varies from 2.69 °C/100 m (zone 26) to 3.9 °C/100 (zone 3).

3. Correlation between reservoir temperatures and pressures

With a visual comparison of the zonal maps compiled by the author, you can note the similarity between the location of the thermal and baric zones. This observation points to the fact that there is a relationship between reservoir pressures and temperatures.

In order to clarify the relationship between these parameters, a graph of the change of reservoir pressures as a function of temperature was constructed (Figure. 3). According to thermodynamic laws, an increase in temperature should result in an increase of reservoir pressure. As can be seen from the graph, the reservoir pressures increase regularly, as the reservoir temperatures increase. This is observed up to reservoir temperatures around 100 °C. When this value is exceeded, the linear dependence is violated and the nature of the dependence takes an exponential form.
During the further analysis of the collected information, it was found that the significant deviations of the P (T) function form linear form are associated with Urengoy, Sterkhovoy, Severo-Purovsky, Yamburg, Kharasaveysky, Bovanenkovskoye, Malyginsky and a group of Tambeyskoye oil and gas fields.

For the Urengoy, Sterkhovoy, Severo-Purovsky and Yamburg oil and gas fields, the deviation of the P (T) function from the linear form is explained by the fact that the measurements were taken in the deposits of the Achimov strata. Lenticular Achimov reservoirs form inside themselves an overpressure due to their hydrodynamic isolation. High reservoir temperatures affect the hydrocarbons contained within the Achimov strata, which expand and still can not leave the isolated volume of the reservoir [20].

Within the Kharasavey, Bovanenkovskoye, Malyginsky and Tambeyskoye oil and gas fields, the deviation of the P (T) function from the linear form is recorded in the Middle Jurassic and Lower Jurassic sediments. These reservoirs are also characterized by hydrodynamic isolation, which explains the deviation detected. A unique phenomenon is the Kharasaveyskoe oil and gas field, where the deviation of the P (T) function from the linear form is observed at shallow depths in hydrodynamically open reservoirs of the Cretaceous age.

The nature of high reservoir pressures and temperatures this field has not yet been established. But according to the author, high reservoir pressures and temperatures can be explained by the proximity of this deposit to the Cenozoic zone of tectonic activation in the Arctic Ocean. Perhaps within this field there is a hydrodynamic connection between deep subsoil and productive layers. The incoming hot fluids from deep zones cause high reservoir temperatures and reservoir pressure.

4. Conclusion
The studies carried out by the author established a direct relationship between reservoir pressures and temperatures within the northern part of Western Siberia. The absence of an explicit relationship between these parameters is revealed in the Jurassic and Achimov reservoirs, and is explained by the features of the geological structure.
For the first time author perform a unique thermobaric zoning of northern part of West Siberia. Zonation allow to observe the connection between reservoir pressures and temperatures within localized areas.

Dependences of reservoir pressures and temperatures on depth, as well as reservoir pressures on temperature, and also the zoning performed (Figure 2) can be used to predict these parameters within poorly studied regions to ensure drilling safety. The results of the study can be also used for oil and gas resources estimation.

5. References
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