Overview of Lower Cretaceous Achimov Formation: Physical Properties and Their Distribution Pattern in West Siberian Basin, Russia

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The Achimov Formation is one of the most important oil- and gas-bearing strata in the West Siberian basin in Russia. The total estimated reserves of this stratum exceed one billion tons. The formation was first explored in 1981, but it remains largely undeveloped due to its deep burial depth and poor physical properties. Therefore, further research on the genetic mechanisms and distribution characteristics of the reservoirs in the formation can contribute to its further exploitation. The Achimov Formation is dominated by fine- to medium-grained sandstones interbedded with shale. Based on analysis of well logging data, hand specimens, and previous research, this study analyzed the properties of three members (Ach1, Ach2, and Ach3) of the Achimov Formation and summarized their distribution patterns. Research on reservoir rocks from different oil and gas fields reveals varying physical properties across the formation with permeability and porosity increasing from the northern to central areas and decreasing from the central to the southern areas. Burial depth is one of the major controlling factors for reservoir properties in the formation. Reservoirs in both the northern and southern parts of the formation are buried deeper than those in the central areas, resulting in a disparity in reservoir quality.

1. Introduction

Unconventional reservoirs, typically those with a low permeability and great burial depth, are gaining more attention in the global oil and gas industry. Russia, as one of the largest oil producers worldwide, is no exception to this trend. Formations with oil/gas potential that are characterized by complicated geological structures and less favorable physical properties (for hydrocarbon accumulation) are being thoroughly studied to improve exploration activities in many petrolierous areas in Russia.

The Achimov Formation in the Lower Cretaceous is one of the most perspective and complex exploration and exploitation object in Russian nowadays. There are many researches about depositional conditions of Achimov Formation and other low permeability reservoir. Previous studies generally agreed that the Achimov Formation was deposited in an uncompensated deep marine basin and that the interbedded sandstones and shale in the Formation are correlated with those on a Berriasian-Valanginian shelf in the late Cretaceous, and source rocks of these deposits are mainly continental sandstones from east of the basin ([1–3]; Nezhdanov et al., 2000). In current research, some new and more specific viewpoints about genetic mechanism are put forward. Some research proposed that the necessary conditions in some sequences and zones for the formation of low porosity and permeability reservoirs in fine-grained sedimentary system are (1) good sealing and preservation conditions, (2) high
pressure coefficient, and (3) thin-layered shale facies of high TOC [4]. An SPE program about a case study of Achimov Formation concluded that the formation is formed during an active alongshore sediment transport and their sources—single clastic influx came from river delta [5]. By using the results of sedimentology core analysis, other investigator confirmed that Achimov deposits were formed in high efficiency systems of submarine fans in relatively deep-sea basin [6].

The grain size of Achimov Formation is heterogeneous, and its geological structure is also relatively complex. The genesis and detail of geological structure of these deposits are still ambiguous [7]. In addition, the distribution patterns of Achimov sandstones physical properties and their controlling factors are still a subject to discussions. Some scholars believe that Achimov Formation was accompanied by sementation faults, which in this case influence fluid and hydrocarbon migration [8]. While other research proposed that reservoir properties of Achimov sandstones are mainly confined to the depocenter of cliniforms [9].

In this study, reservoir properties of three members (Ach1, Ach2, and Ach3) of the Achimov Formation are described, and their distribution patterns are summarized based on analysis of well logging data, hand specimens, and previous researches.

2. Geological Settings

The Lower Cretaceous Achimov Formation is located in the West Siberian petroleum basin near the east flank of the Ural Mountains (Figures 1(a) and 1(b)). The geological structure of the study area is relatively complicated because of multistage tectonic movements have significant influence on this region. More than 900 oil and gas fields have been discovered in the basin. The main oil and gas fields are listed in Figure 1(c).

Mesozoic sedimentations are dominated by sandstones and shales (Figure 2). In the latest Jurassic-earliest Cretaceous time, in the West Siberian basin emerged a deep-water anoxic depression and as a result formed black, organic-rich siliceous shale in the deep-sea basin [11]. Thus, far. F. G. Gurari was the first to describe this Lower Cretaceous sedimentation unit, and he named it Achimov. The burial depth of Achimov Formation (Ach1, Ach2, and Ach3) in the study area is varied from 2600 to 2900 m. The Achimov Formation is distributed across the West Siberian petroleum basin, and lithologically, the formation mainly consists of fine- to medium-grained sandstones interbedded with shale.

3. Oil- and Gas-Bearing Properties and Exploration History

The Achimov Formation is one of the most promising and perspective strata in Russian petroleum exploration and exploitation. The estimated petroleum reserves in the Achimov Formation in the study area exceed one billion tons. Exploration and exploitation of the formation began in 1981 and can be divided into several steps. The first step began in 1981 and ended in 2002, and the first well in the formation
was drilled in 1981. In this step, efficiency of exploitation was low, and a limited number of wells were drilled.

The second step was from 2003 to 2008. Many wells were drilled in the study area, and the exploitation efficiency of the period was high. Water injections were used in some of the oil and gas fields in the formation to maintain pressure in producing strata.

From 2009 to 2011, the northern part of the study area was explored.

The final step started in 2011 and extends to the present. Exploration activities moved to the eastern part of the study area.

The Achimov Formation, buried deeply underground, is characterized by its low porosity and permeability. Table 1 shows the geological and physical characteristics of the productive reservoirs of the formation in the West Siberian petroleum basin. The porosity and permeability of the sandstone are among the most important properties for a reservoir quality assessment, which justifies studying these properties and reservoir distribution patterns in the formation for future exploration activities.

4. Lithological Characteristics

The East Medwthya oil and gas field is one of the largest in the area, and its stratigraphic features are extremely representative. The sandstone- and shale-dominated Achimov Formation contains the primary oil- and gas-bearing layers...
in the East Medwthya oil and gas field. A geological cross-section based on well logging data and seismic data of the formation shows that the layers with greater thicknesses have superior physical properties (Figure 3). In general porosity and permeability of these thicker layers, respectively, exceed 18% and 5 mD. It also indicates that the hydrocarbon reservoirs in the formation are predominately distributed in specific strata that are thicker and exhibit superior physical properties.

The Achimov Formation is dominated by fine- to medium-grained sandstone with grain sizes ranging between 0.10 and 0.14 mm and coarse-grained aleurolite with grain

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**Table 1:** Geological and physical characteristics of the Achimov Formation reservoirs in the West Siberian petroleum basin (modified based on [12]).

| Parameters                              | Unit   | Value |
|-----------------------------------------|--------|-------|
| Average depth of reservoirs             | m      | 2900  |
| Average effective thickness of reservoirs | m      | 18.9  |
| Porosity                               | %      | 18    |
| Average initial oil saturation         | %      | 52    |
| Permeability                           | mD     | 3     |
| Average permeability in the vertical direction | mD     | 0.1   |
| Content of sandstone                   | %      | 27    |
| Density of water under standard conditions | kg/m³ | 1016  |
| Viscosity of water under reservoir conditions | mPa·s | 0.34  |
| Initial stratum temperature            | °C     | 95    |
| Saturated pressure of stratum          | MPa    | 9     |
| Density of the oil under reservoir conditions | kg/m³ | 758   |
| Density of crude oil under standard conditions | kg/m³ | 844   |
| Initial gas content in oil             | m³/t   | 74.3  |
| Volumetric coefficient of petroleum    | m³/m³  | 1.26  |

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**Figure 3:** Geological cross-section of the Achimov Formation in the East Medwthya oil and gas field from west to east (after [13]): (1) regional clinoform borders, (2) regional clinoforms (a) Cheuskinsky and (b) Savusky, (3) Bazhenov Fm., (4) silty-sandy Achimov Fm in (a) tight layers and (b) water-saturated layers and oil and gas reservoirs (5, 6), (5) oil, (6) gas, and (7) promising hydrocarbon traps.
sizes varying from 0.06 to 0.09 mm. The sandstones are light grey to grey and are moderately to fully mature. Siliceous and argillaceous cementation are the main cementation type of Achimov Formation. Measurements show that cementation makes up 5% to 12% of the samples from the study area.

Sandstone and shale interbeds can be identified in Figure 4. Parallel and cross bedding were also recognized in the formation (Figures 4(c) and 4(d)), indicating changing hydrodynamic environments. The relatively small-scale fine-grained bedding may reveal a weak hydrodynamic environment. In Figure 4, samples “a” and “c” are from well 822 at depth of 2831 and 2847 m. Sample “b” is from well 410 at depth of 2950 m, and sample “d” is from well 426 at depth of 2702 m.

5. Reservoir Properties

The oil- and gas-bearing potentials of the Achimov Formation predominately depend on the lithological composition, porosity, permeability, temperature, and pressure of its reservoir rocks. Of these factors, porosity and permeability are the two most important measurements to assess reservoir quality. Table 2 lists the two properties measured for samples from the Achimov Formation in the Alekhinskoe Field.

Member Ach3 has the lowest porosity and permeability and highest water conservation capacity. The water conservation capacity may also occupy pore space, which can make the reservoir properties worse. The buried depth of member Ach3 is the largest of all the members, which may indicate

| Members | Porosity (%) | Permeability (mD) | Water conservation capacity (%) | Average depth (m) |
|---------|--------------|-------------------|---------------------------------|------------------|
| Ach1    | 16.3%        | 3.9               | 55                              | 2671             |
| Ach2    | 16.5%        | 5.0               | 56                              | 2682             |
| Ach3    | 16%          | 3.5               | 60                              | 2694             |

Table 2: Average porosity and permeability of the Achimov Formation in the Alehins Field (after [10]).
that the stratum depth significantly influences reservoir properties.

The Achimov Formation is distributed across the West Siberian petroleum basin, but it is concentrated in the central and eastern parts of the study area (Figure 1(c)). An investigation into the oil and gas fields in the area revealed that the buried depth of the Achimov Formation decreases gradually from the northern to central areas and increases slowly from the central to southern areas. The central part contains the shallowest oil/gas fields. The three oil fields, Konitlorskoe (III), Alekhinskoe (IV), and East Studenoe (V), in the central part are shallower than those in other parts.

The porosity of the Ach1 in most of the fields in the study area ranges between 15.0% and 16.5%. However, the formation (Ach1, Ach2, and Ach3) in the Konitlorskoe field has an average porosity of 19.1%, which is higher than that of any other field in the study area. Three fields (Konitlorskoe, Malobalykskoe, and East Studenoe) contain a part of the formation that exhibits a higher porosity. Ach3, which is buried deeper than the other two members (Ach1 and Ach2), exhibits the lowest porosity for hydrocarbon accumulation because of stronger compaction caused by deeper depth (Table 3).

The differences in permeability between these oil and gas fields are substantial. The Ach1 and Ach2 members have the highest permeability in the West Kotukhtinskoye and East Studenoe oil and gas fields. Ach3 has the lowest permeability (from 1 mD to 2 mD) of all the oil and gas fields. The maximum permeability is generally observed in samples from northern Middleobck in the study area (Figure 5 and Table 3).

The results indicate that the physical properties of the Achimov Formation are the most favorable for oil and gas pooling in the central part of the formation—relatively higher porosity and permeability observed in the East Studenoe oil and gas field (V) and physical properties deteriorate

| Members | Porosity (%) | Permeability (mD) | Water conservation capacity (%) | Average depth (m) |
|---------|--------------|-------------------|-------------------------------|-----------------|
| Vyintoskoye oil and gas field (I) | | | | |
| Ach1 | 16.5 | 3.8 | 52.6 | 2873 |
| Ach2 | 17.0 | 1.8 | 53.0 | 2885 |
| Ach3 | 16.0 | 1.2 | 64.0 | 2905 |
| West Kotukhtinskoye oil and gas field (II) | | | | |
| Ach1 | 16.3 | 4.0 | 48.5 | 2806 |
| Ach2 | 17.0 | 5.5 | 56.0 | 2818 |
| Ach3 | 15.7 | 1.5 | 63.0 | 2830 |
| Konitlorskoe oil and gas field (III) | | | | |
| Ach1 | 19.0 | 3.8 | 53.0 | 2386 |
| Ach2 | 20.0 | 1.8 | 55.0 | 2587 |
| Ach3 | 18.3 | 1.2 | 65.0 | 2615 |
| East Studenoe oil and gas field (V) | | | | |
| Ach1 | 16.9 | 4.0 | 51.9 | 2668 |
| Ach2 | 18.0 | 5.5 | 55.5 | 2727 |
| Ach3 | 16.0 | 1.5 | 65.4 | 2751 |
| West Kamynskoe oil and gas field (VI) | | | | |
| Ach1 | 15.0 | 2.0 | 53.0 | 2792 |
| Ach2 | 16.0 | 2.5 | 55.7 | 2810 |
| Ach3 | 15.5 | 1.0 | 63.8 | 2835 |
| Priobskoe oil and gas field (VII) | | | | |
| Ach1 | 16.0 | 3.8 | 55.0 | 2632 |
| Ach2 | 16.0 | 3.8 | 60.8 | 2687 |
| Ach3 | 15.4 | 1.2 | 62.0 | 2779 |
| Malobalykskoe oil and gas field (VIII) | | | | |
| Ach1 | 16.9 | 1.0 | 47.9 | 2595 |
| Ach2 | 18.0 | 3.0 | 51.2 | 2642 |
| Ach3 | 16.5 | 1.0 | 65.4 | 2696 |
| West Varyoganskoye oil and gas field (IX) | | | | |
| Ach1 | 15.9 | 3.8 | 50.8 | 2798 |
| Ach2 | 17.0 | 3.8 | 56.5 | 2826 |
| Ach3 | 16.0 | 1.2 | 65.4 | 2856 |
Figure 5: Charts of the porosity and permeability of different members (Ach1, Ach2, and Ach3) in the Achimov Formation in various oil and gas fields (after [10]) (Vintentskoye (I), West Kotukhtinskoye (II), Konitlorsko (III), Alekhinskoe (IV), East Studenoe (V), West Kamynskoe (VI), Priobske (VII), Malobalyskoe (VIII), and West Varyogansko (IX)).
from central part to both northward and southward. The pore structure is related to the burial depth, and as a result, the variation of burial depth might have a significant influence on the porosity and permeability of reservoir [15].

The burial depth of the Achimov Formation gradually decreases and then increases along the north-central-south direction, and it exerts a significant influence on the physical properties of the formation in the study area. Compared with the central part, which exhibits superior physical properties, the formation in the south and north parts has inferior physical properties as a result of the more intensive compaction caused by the greater depths. It is very likely that, during the diagenesis process, the compaction and increasing burial depth destroyed pore space and reduced the porosity and permeability of the formation rocks that are distributed northward and southward in the study area. Therefore, burial depth is identified as one of the major controlling factors, which influence the distribution patterns of the reservoir properties of Achimov Formation.

### 6. Conclusions

The Achimov Formation is dominated by fine- to medium-grained sandstone interbedded with shale. Parallel and cross beddings can be clearly identified in the reservoir rocks, and these fine-grained and small-scale beddings imply a weak hydrodynamic environment. Based on analysis of well logging data and hand specimens, this article revealed the average porosity and permeability of the Achimov Formation (Ach1, Ach2, and Ach3) in the primary oil and gas fields across the study areas. Result suggested that reservoir porosity of the Achimov Formation is relatively low because of not only weak hydrodynamic environments but also its greater buried depth, which strongly influence the process of digenesis. Moreover, research on the lithological characteristics and reservoir properties of the Achimov Formation in the west of the West Siberian petroleum basin also demonstrates that the physical properties within the study area vary greatly and regularly. Data shows that the physical properties of rocks from the formation in the study area are the most favorable for oil and gas pooling in the central part and that they deteriorate toward the northern and southern parts, where the burial depth increases, respectively. The changing of burial depth is identified as one of the major controlling factors, which influence the distribution patterns of the reservoir properties of Achimov Formation.

### Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

###Conflicts of Interest

The authors declare that they have no conflicts of interest.

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