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# The study of structural-mechanical properties of complex oil-water emulsions of the deposits in Western Kazakhstan

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**Abstract**

Oil in the Caspian basin is characterized as viscous and heavy with a high content of metals, especially Vanadium and Nickel, which are associated in the oils with asphalt-resinous components. These properties of the oil reduce its recovery index. These properties and methods of oil production optimization were considered on the basis of the North Buzachi oil and gas region of the Republic of Kazakhstan. The structural and mechanical properties of water-oil emulsions of crude oil were experimentally studied. Based on the measured in vitro parameters, the values of shear stress at wall shear rate were calculated, and then the flow curves were built for different temperatures and oil-water proportions. As a result, the regularities of the changes of rheological properties are determined depending on water content and temperature, and the resulting formula is obtained that allows determining the values of effective viscosity complex of oil-water emulsions. On the basis of the obtained results, the optimization of technological modes of crude oil preparation can be carried out in this field for further transportation and processing in the different operation periods.

**Key words**: Water-oil emulsion, de-emulsification, rheology, heavy oil, North Buzachi oil and gas region

## Introduction

The Republic of Kazakhstan is one of the leaders in the production of hydrocarbons (Matveev et al., 2016). However, the oil extracted in Kazakhstan, especially in the North Buzachi oil and gas region, has a high viscosity and because of this falls into the category of unconventional resources with a high content of metals associated with asphalt-resinous components (Tarasov et al., 2004; Gubaydullin, 2004; Ametov et al., 1985). This problem is common to all countries, extracting oil in the Caspian basin.

Analysis of the development of North Buzachi oil and gas region indicates a sharp increase of water content at the initial stage of construction due to the excessively large difference in the rheological characteristics of the reservoir oil and water. Consequently, at the bottom of the well and in the trunk, the water-oil emulsion is formed, which can acquire many different states with various physical-mechanical and technological properties. Considerable number of works is devoted to the study of the properties of water-oil emulsions (Kulakov, 1993; Gubaydullin et al., 2004; Emkov and Popovkina, 1996).

Usually, in the design and construction of oil treatment plants, the data on the properties of waterless oil and its emulsions are submitted without taking into account the specifics of the formation and destruction of the emulsion (Zapata et al., 2012; Ushikubo and Cunha, 2014; Binner et al., 2014). Formation of persistent oil-water emulsions during joint movement of oil and water, along with dispersion, is caused by natural emulsifiers in oil (Binks and Tyowua, 2016; Gu et alk., 2014; Zhong et al., 2016). At the same time, the component composition of emulsifiers plays the important role that promotes the formation of strong adsorption film on the surface of water globules.

Oils from North Buzachi, Karazhanbas, Kalamkas, Karaturun, Western Teren-Usec regions and oils from other Western Kazakhstan regions are heavy, asphaltene high-paraffin oils, which have high viscous properties. Asphaltenes and resins in certain thermodynamic conditions, dropping out of the dissolved state, can form various structural environment by forming the adsorption film of various properties on the surface of water droplets. Microscopic studies have shown (Gubaydullin et al., 2004; Gumbatov, 1976; Emkov and Popovkina, 1996) that emulsions of resinous-paraffin oil and emulsions of highly resinous oil with tha asphaltene content are significantly different in terms of resistance and intensity of destruction depending on the conditions of emulsions formation and composition of the adsorption film. Studies have shown that emulsions of resinous-paraffin oil more easily subject to dehydration than the emulsion of highly resinous oil with asphaltene content.

It is noted that the oil of Karazhanbas region has a relatively high emulsifying power (Khabibullina and Prischenko, 1976; Lee et al., 2013; Parkhomchik, 2015). Research on the allocation of emulsifiers and the study of their composition determined that asphaltenes are the main stabilizers of Karazhanbas oil. Asphaltenes and resins contained in the composition of stabilizers, according to the high values of the light absorption coefficient, are condensed aromatic structures with high molecular weight. Asphaltenic nature of the stabilizers and the high value of the adsorption are the main reasons for the high stability of the oil emulsion in Karazhanbas region. Best results on emulsion de-emulsification of Karazhanbas oil were obtained by the thermochemical de-emulsification method with the reagent disolvane 4411 at the processing temperature of 80 ° C. The complete destruction of a 20% emulsion was achieved with the disolvane flowrate of 300 g/t in these conditions.

The analysis of scientific and patent literature and our own research showed that the factors determining the tendency of oils to emulsification are: physico-chemical properties of oil; the temperature of the emulsion formation; salinity of reservoir water; dispersion of water globules.

## Aim of the Study

To consider the features of the oil deposits in the North Buzachi oil and gas region.

## Materials and Methods

Theoretical and methodological basis of research is the theory of sustainable development regulation of the oil industry in a variety of management forms and integration processes of the oil sector development, the works of domestic and foreign experts in the oil industry. The validity and reliability of the study is achieved by the application of scientific methods of analysis.

To achieve this objective, the paper applies the following methods: abstract-logical, analytical, specifically historical, experimental, and economic-statistical. In addition, the methods of dialectical cognition, system approach, economic-statistical, and settlement-constructive approaches were used in the research.

## Results

As it is known, crude oil and the average density do not tend to form stable emulsions. Paraffin oil is characterized by a tendency of the emulsion to hold water in its crystal lattice; therefore, an additional condition in the destruction of emulsions is the melting of this lattice. Oils with a high content of asphaltene-resinous substances (natural emulsifiers) are accompanied by the formation of highly viscous stable emulsions. In the formation of oil and water emulsions, as well as in their destruction, the system temperature plays an important role. Highly resinous oils can form emulsion containing 30-60 % water at temperatures observed in the wellbore and gathering system.

The salinity of reservoir water can also be the main reason for the formation of hard collapsing complex emulsions. Reservoir water produced with the oil and forming a disperse system contains significant amounts of dissolved salts.

The stability of an emulsion largely depends on the dispersion of the emulsion. When driving in flooded oil from the face to the mouth and further for infield pipes, the continuous mixing of oil with water takes place with the formation of persistent emulsions. The main parameters that determine the degree of the emulsion dispersion in the joint movement of water and oil are flow velocity, surface tension on the phase interface and the scale of the surge. The flow velocity in the movement of oil-water mixture varies widely, and, consequently, changes the driving mode of oil-water mixture. Solid particles in the mixture (sand, asphaltenes) can be local sources of turbulization that at a certain value of speed can lead to early turbulization of the entire flow. Thus, the turbulized regime occurs at much lower values of the critical values of the Reynolds number. This leads to an increase of flow pulsation, a reduction in the diameter of the water globules and increases the dispersity of the suspension. Especially large changes of dispersion are observed during the passage of the mixture through choke restricting device and pumping units.

The mentioned features of formation of stable heavy emulsions are of great importance in developing destruction means of complex emulsions.

Great content of asphaltene-resinous substances in the oil greatly affects the conditions of the emulsions formation, stability, and rheological properties. Therefore, in the operation of wells, producing water-oil mixture and infield transport, it is necessary to know the change of rheological parameters of oil from the degree of flooding. Accurate determination of rheological properties of oil-water emulsions makes it possible to choose the technology of operation of flooded oil wells and oil pumping at the design capacity of the pipeline. In addition, the study of structural-mechanical characteristics of emulsions allows solving such issues as de-emulsification complex emulsion, the inside of the pipeline de-emulsification, hydro-transport, etc.

Experimental study of rheological properties of water-oil emulsions were performed on the capillary viscometer. Experiments on the learning curves of the currents were carried out on the oil regions of North Buzachi (borehole No. 130), Karazhanbas (borehole No. 108), Karaturin (borehole No. 1) at different values of temperature and water content.

$$P = \frac{\Delta PR}{2l}, \qquad V = \frac{4Q}{\pi R^3}, \tag{1}$$

The emulsions were prepared by mixing oil with an artificially prepared reservoir-water emulsifier of "Zenith" type (2800 rpm) for 20-30 minutes. After pouring and incubation in the viscometer, we registered the dependence of flow rate of fluid passing through the capillary, from the pressure at its ends. The obtained data were processed in consistent variables: where P - shear stress on walls, V - shear rate.

The results of calculations for North Buzachi oil region (borehole No. 130) at different temperatures and water relations are shown in tables 1-6.

Based on the obtained data, we constructed rheological curves (rheograms) of flow, which has shown that with the increase of water content in oil, the viscosity increases, changing the nature of flow curve.

**Table 1: Values of P and V for 22% water-oil emulsion of North Buzachi region**

| 20ºC | | 40ºC | | 60ºC | |
|---|---|---|---|---|---|
| P, pascal | V, c-1 | P, pascal | V, c-1 | P, pascal | V, c-1 |
| 47,5 | 5,9 | 56,8 | 51,8 | 30,7 | 118,8 |
| 116,4 | 16,7 | 121,0 | 121,0 | 90,3 | 205,2 |
| 219,7 | 34,3 | 190,9 | 205,2 | 113,6 | 428,8 |
| 324,0 | 45,3 | 256,0 | 284,0 | 153,6 | 577,8 |
| 429,2 | 58,3 | 288,6 | 361,8 | 186,2 | 716,0 |
| 627,5 | 78,3 | 409,6 | 437,4 | 251,4 | 977,4 |
| 702,9 | 105,1 | 470,2 | 518,4 | 290,5 | 1112,4 |
| 887,2 | 134,2 | 544,6 | 577,8 | 367,7 | 1400,8 |
| 1195,4 | 167,7 | 605,2 | 669,6 | 431,1 | 1688,0 |
| 1319,2 | 208,3 | 702,9 | 783,0 | 569,8 | 2187,0 |
| 1572,5 | 246,3 | 819,3 | 898,6 | 644,3 | 2454,8 |
| 1759,6 | 287,1 | 1005,5 | 1107,0 | - | - |
| 2017,5 | 333,6 | 1098,6 | 1217,2 | - | - |
| 2222,3 | 371,6 | 1294,1 | 1434,2 | - | - |
| | | 1322,0 | 1601,6 | - | - |

**Table 2: Values of P and V for 30% water-oil emulsion of North Buzachi region 20-50 ºC**

| 20ºC | | 30ºC | | 40ºC | | 50ºC | |
|---|---|---|---|---|---|---|---|
| *P, pascal* | *V, $c^{-1}$* | *P, pascal* | *V, $c^{-1}$* | *P, pascal* | *V, $c^{-1}$* | *P, pascal* | *V, $c^{-1}$* |
| 136,9 | 12,6 | 48,4 | 8,0 | 10,2 | 6,0 | 14,3 | 11,2 |
| 245,8 | 18,3 | 119,2 | 26,9 | 123,8 | 88,1 | 153,7 | 120,1 |
| 464,6 | 47,7 | 185,3 | 46,0 | 232,8 | 164,9 | 458,0 | 289,7 |
| 682,4 | 64,2 | 255,1 | 68,8 | 328,6 | 237,1 | 508,5 | 381,7 |
| 904,9 | 87,7 | 359,4 | 106,8 | 459,9 | 339,4 | 663,1 | 459,9 |
| 1145,1 | 116,3 | 464,6 | 131,7 | 669,4 | 498,6 | 912,9 | 669,4 |
| 1326,7 | 145,8 | 566,0 | 166,8 | 900,3 | 684,9 | 1313,5 | 934,7 |
| 1581,8 | 181,8 | 674,0 | 205,5 | 1100,4 | 864,1 | 1619,6 | 1148,9 |
| 1795,0 | 209,3 | 839,8 | 269,7 | 1340,6 | 1043,9 | 1925,2 | 1358,3 |
| 2017,5 | 245,2 | 1079,0 | 362,2 | 1558,5 | 1259,5 | 2328,4 | 1558,5 |
| 2231,6 | 280,6 | 1323,9 | 460,9 | 1763,3 | 1467,7 | 2681,3 | 1801,5 |
| - | - | 1554,8 | 548,6 | 2230,7 | 2059,0 | 3121,1 | 2107,8 |
| - | - | 1751,2 | 621,3 | - | - | - | - |
| - | - | 1984,0 | 716,9 | - | - | - | - |

**Table 3: Values of P and V for 30% water-oil emulsion of North Buzachi region 60-80 ºC**

| 60ºC | | 70ºC | | 80ºC | |
|---|---|---|---|---|---|
| *P, pascal* | *V, $c^{-1}$* | *P, pascal* | *V, $c^{-1}$* | *P, pascal* | *V, $c^{-1}$* |
| 11,2 | 23,9 | 11,2 | 39,4 | 22,3 | 121,6 |
| 128,5 | 311,0 | 58,7 | 185,8 | 63,3 | 238,1 |
| 255,1 | 555,1 | 158,3 | 547,6 | 132,2 | 604,8 |
| 350,1 | 732,2 | 273,7 | 827,3 | 241,1 | 1094,0 |
| 535,3 | 1063,8 | 467,4 | 1679,4 | 311,0 | 1425,6 |
| 702,9 | 1419,1 | 694,5 | 2602,8 | 454,3 | 2106,0 |
| 903,1 | 2340,4 | 880,7 | 3283,2 | 563,3 | 2610,4 |
| 1113,5 | 2662,2 | 1103,2 | 4309,2 | 673,1 | 3196,8 |
| 1368,6 | 3190,3 | 1374,2 | 5032,8 | 776,5 | 3499,2 |
| 1565,9 | 3898,8 | 1545,5 | 5799,6 | 903,1 | 4222,8 |
| 1824,8 | 5464,8 | 1761,5 | 6706,8 | 1019,4 | 4622,4 |
| 2314,5 | 5994,0 | - | - | 1148,9 | 5427,0 |
| - | - | - | - | 1239,2 | 6037,2 |
| - | - | - | - | 1325,7 | 6566,4 |

**Table 4: Values of P and V for 36% water-oil emulsion of North Buzachi region**

| 20ºC | | 40ºC | | 60ºC | |
|---|---|---|---|---|---|
| *P, pascal* | *V, $c^{-1}$* | *P, pascal* | *V, $c^{-1}$* | *P, pascal* | *V, $c^{-1}$* |
| 119,2 | 5,1 | 45,6 | 11,4 | 11,2 | 12,3 |
| 224,4 | 7,5 | 115,4 | 33,4 | 45,6 | 49,1 |
| 328,6 | 14,7 | 185,3 | 54,4 | 81,0 | 87,7 |
| 446,9 | 15,9 | 289,5 | 85,0 | 117,3 | 111,1 |
| 555,8 | 18,0 | 428,3 | 126,3 | 150,8 | 169,3 |
| 664,7 | 23,8 | 530,7 | 157,5 | 186,2 | 203,8 |
| 778,3 | 28,8 | 675,9 | 202,1 | 220,6 | 248,7 |
| 887,2 | 31,4 | 876,1 | 272,4 | 255,1 | 291,5 |
| 1010,1 | 42,6 | 1062,3 | 332,0 | 289,5 | 317,4 |
| 1215,0 | 50,4 | 1241,0 | 397,5 | 324,0 | 333,4 |
| 1476,6 | 62,9 | 1389,1 | 453,0 | 358,4 | 394,1 |
| 1582,7 | 71,0 | 1559,4 | 515,4 | 432,9 | 478,4 |
| 2017,5 | 81,2 | 1754,9 | 599,2 | 498,1 | 557,0 |
| 2204,6 | 95,6 | 1930,0 | 664,5 | 567,9 | 614,2 |
| 2450,4 | 123,3 | 2099,4 | 738,7 | 639,6 | 755,4 |
| - | - | 2252,1 | 771,3 | 702,0 | 794,2 |

**Table 5: Values of P and V for 50% water-oil emulsion of North Buzachi region**

| 20ºC | | 40ºC | | 60ºC | |
|---|---|---|---|---|---|
| *P, pascal* | *V, $c^{-1}$* | *P, pascal* | *V, $c^{-1}$* | *P, pascal* | *V, $c^{-1}$* |
| 149,9 | 1,7 | 141,5 | 17,1 | 11,2 | 5,6 |
| 290,5 | 3,0 | 228,1 | 30,2 | 120,1 | 74,8 |

| 20ºC | | 40ºC | | 60ºC | |
|---|---|---|---|---|---|
| 475,7 | 5,7 | 338,0 | 46,5 | 229,0 | 124,0 |
| 661,9 | 10,5 | 446,9 | 63,2 | 338,0 | 180,0 |
| 848,1 | 15,2 | 555,8 | 82,2 | 446,9 | 247,2 |
| 1034,3 | 20,3 | 664,7 | 104,4 | 555,8 | 312,8 |
| 1220,5 | 25,1 | 773,7 | 117,4 | 664,7 | 376,6 |
| 1416,1 | 30,1 | 882,6 | 136,4 | 786,7 | 467,9 |
| 1611,6 | 34,7 | 1100,4 | 176,5 | 882,6 | 538,7 |
| 1769,8 | 38,7 | 1319,2 | 220,9 | 1122,8 | 699,9 |
| 1974,7 | 47,6 | 1537,1 | 265,8 | 1327,6 | 863,4 |
| 2160,9 | 52,5 | 1754,9 | 313,4 | 1546,4 | 1032,6 |
| 2365,7 | 55,8 | 1982,1 | 362,1 | 1777,3 | 1205,8 |
| 2634,7 | 63,3 | 2196,2 | 415,2 | 1990,5 | 1447,3 |
| 2755,8 | 67,3 | 2370,3 | 496,8 | 2248,4 | 1616,0 |

**Table 6: Values of P and V for 60% water-oil emulsion of North Buzachi region**

| 20ºC | | 40ºC | | 60ºC | |
|---|---|---|---|---|---|
| *P, pascal* | *V, c$^{-1}$* | *P, pascal* | *V, c$^{-1}$* | *P, pascal* | *V, c$^{-1}$* |
| 1032 | 6,91 | 93 | 5,08 | 24 | 7,99 |
| 1223 | 6,48 | 196 | 9,72 | 28 | 11,02 |
| 1423 | 8,21 | 289 | 16,20 | 80 | 19,98 |
| 1610 | 9,40 | 396 | 24,30 | 115 | 30,67 |
| 1796 | 11,56 | 470 | 29,59 | 184 | 49,57 |
| 1912 | 11,99 | 563 | 36,83 | 254 | 92,23 |
| 1991 | 14,15 | 670 | 51,62 | 324 | 100,33 |
| 2075 | 14,90 | 852 | 61,02 | 394 | 108,43 |
| 2159 | 15,88 | 1047 | 78,84 | 465 | 133,38 |
| 2350 | 17,71 | 1229 | 96,12 | 530 | 153,25 |
| 2522 | 20,09 | 1397 | 113,18 | 607 | 175,72 |
| 2722 | 22,90 | 1685 | 142,99 | 687 | 205,31 |
| - | - | 2094 | 189,32 | 847 | 258,12 |
| - | - | 2345 | 220,54 | 1029 | 329,51 |
| - | - | 2606 | 254,66 | 1327 | 464,94 |
| - | - | - | - | 1592 | 567,00 |

**Table 7: Values of P and V for 70% water-oil emulsion of North Buzachi region**

| 20ºC | | 40ºC | | 60ºC | |
|---|---|---|---|---|---|
| *P, pascal* | *V, c$^{-1}$* | *P, pascal* | *V, c$^{-1}$* | *P, pascal* | *V, c$^{-1}$* |
| 765,3 | 3,6 | 196,4 | 5,5 | 67,8 | 9,2 |
| 909,6 | 4,6 | 294,2 | 16,8 | 153,3 | 21,1 |
| 1049,2 | 5,5 | 392,0 | 12,5 | 205,8 | 31,4 |
| 1188,9 | 6,4 | 578,2 | 23,3 | 294,2 | 44,1 |
| 1314,6 | 7,7 | 759,7 | 30,7 | 392,0 | 58,6 |
| 1454,2 | 9,2 | 959,9 | 41,8 | 455,7 | 69,4 |

| 20ºC | | 40ºC | | 60ºC | |
|---|---|---|---|---|---|
| 1603,2 | 9,3 | 1141,4 | 59,5 | 564,2 | 83,1 |
| 1743,8 | 10,0 | 1323,0 | 74,6 | 661,9 | 111,0 |
| 1873,2 | 12,6 | 1499,8 | 83,1 | 759,7 | 142,1 |
| 2011,9 | 13,0 | 1672,1 | 98,6 | 941,2 | 171,5 |
| 2158,1 | 14,5 | 1881,6 | 106,7 | 1136,8 | 225,6 |
| 2301,4 | 15,6 | 2067,8 | 111,9 | 1309,0 | 272,9 |
| 2532,3 | 18,9 | 2244,6 | 134,8 | 1499,8 | 334,9 |
| 2710,1 | 20,0 | 2440,2 | 155,6 | 1686,0 | 396,9 |
| - | - | 2603,1 | 166,5 | 1872,2 | 466,5 |
| - | - | 1550,1 | 1654,6 | - | - |

According to the results of experimental studies, the viscosity decreases with increasing shear rate, which is typical for pseudoplastic liquids. Therefore, to describe the rheological curves of heavy emulsions, we can establish an empirical functional relation in the form of an exponential law of Ostwald De Vale:

$$\tau = k\dot{\gamma}^{n} \quad (2)$$

Due to the fact that the fluid rheological model is often unknown in advance or that the certain ranges of strain rate require different models, and mathematical analysis of models is impeded, it seems more convenient to use the measured values of costs and pressure drops in the capillary viscometer – a Metzner-Reed generalization. For this reason, we create the dependence of P and V. As this curve depends only on the rheological characteristics of the liquid, it can be used to calculate pressure loss in any piping. The shear rate at the pipe wall is determined by the formula:

$$-\left(\frac{dv}{dr}\right)_w = \frac{3n'+1}{4n'}\left(\frac{8v}{d}\right), \quad (3)$$

Where

$$n' = \frac{d\ \ln\left(\frac{\Delta PR}{2l}\right)}{d\ \ln\left(\frac{4Q}{\pi R^3}\right)}. \quad (4)$$

Therefore,

$$P = k'V^{n'} \quad (5)$$

Where

$$n = n', \qquad k = k'\left(\frac{4n'}{3n'+1}\right)^{n''} \quad (6)$$

Using experimental data for oil deposits in North Buzachi region, shown in tables 1 - 6, we have calculated the values k' and n'. The calculation results are shown in table 7.

The table shows that the exponent n' decreases with the increase of water content in oil, which shows the increasing non-Newtonian behavior of the oil. In addition, with the increase of temperature, n' increases.

**Table 8: Values of k’ and n’ at different water contents in the oil depending on the temperature**

| Water content in oil | $k'$, $pascal \cdot c^{n'}$ | $n'$, $c^{-n'}$ | $k'$, $pascal \cdot c^{n'}$ | $n'$, $c^{-n'}$ | $k'$, $pascal \cdot c^{n'}$ | $n'$, $c^{-n'}$ |
|---|---|---|---|---|---|---|
| 22% | 8,7175 | 0,9442 | 1,2121 | 0,9555 | 0,3458 | 0,9620 |
| 30% | 17,7609 | 0,8376 | 1,9279 | 0,9380 | 0,5776 | 0,9578 |
| 36% | 32,1820 | 0,9282 | 4,6201 | 0,9320 | 0,9837 | 0,9863 |
| 50% | 113,5400 | 0,7493 | 12,6780 | 0,8564 | 12,6780 | 0,8564 |
| 60% | 317,8800 | 0,6960 | 27,5770 | 0,8280 | 27,5770 | 0,8280 |
| 70% | 299,1200 | 0,7367 | 47,5820 | 0,7830 | 12,0990 | 0,8369 |
| 30% | 30 ºC | | 50 ºC | | 70 ºC | |
| | 7,4060 | 0,8460 | 0,8528 | 0,9419 | 0,3462 | 0,9708 |

The results show that water-oil emulsions of heavy oils show the structural and mechanical properties even at high temperatures at certain proportions of water in the oil. For example, when water content in oil is 22-36 % and a temperature is 40°C, flow curves have properties of the power fluid, and at 60°C – the degree of deviation from Newtonian behavior is low (n≈0,96). For water-oil emulsions with high water content (70 %), structural properties are maintained from 20°C to 60°C.

With the rise of water content, k’-factor increases characterizing the degree of consistency. The temperature increase leads to a decrease in k’. This confirms the assertion that the temperature increase contributes to a partial destruction of the structure, thereby reducing shear resistance.

Construction of the region without taking into account possible improvements in the design of treatment plants to ensure their efficient operation at various stages of development will be marginal due to possible large losses of oil. Therefore, under the expected conditions, preparation of complex emulsion systems requires comprehensive study of their properties. In this regard, multilateral study of the complex emulsion systems has important economic value, aimed at ensuring high-quality raw materials and reducing excess losses of hydrocarbons.

Currently, the rheology of emulsions has been studied insufficiently, taking into account the physico-chemical composition, concentration and solubility of the continuous and dispersed phases, the hydrodynamic interactions between the droplets, floculations, and the distribution of droplets by size, etc.

Numerous theoretical and experimental works are devoted to the determination of the emulsions and suspensions viscosity. One of the first works in this field belongs to A. Einstein, who derived a formula in the study of the viscosity of dilute suspensions that contain spherical liquid particles:

$$\mu_{em}=\mu_{cp}(1+2,5ep) \quad (7)$$

where $\mu_{cp}$ and $\mu_{em}$ are the dynamic viscosity of the continuous phase of the emulsion respectively. Hereinafter, Kinghem has proposed the formula (Khappel and Brennerm, 1976):

$$\mu_{em}=\mu_{cp}(1+2,5\varphi+7,5\varphi^2+\ldots) \quad (8)$$

The study of structural-mechanical properties of paraffinic oils of the Perm region was conducted on the rotary viscometer SV-2. Analysis of experimental results shows that for paraffinic oils of Batyrbay, Tanyp, Kuzmin, and Yuzhansky deposits, the viscosity of oil-water emulsions increases insignificantly with increasing water content in oil up to 30 %, and then reaching a maximum, the viscosity steeply decreases. Maximum viscosity values for these regions were obtained by water content of 60-70% (at temperature t=5 ° C).

To calculate the viscosity, the formula is suggested (Khappel and Brennerm, 1976):

$$\mu = A_{em} \cdot \exp\left[ b\left[\ln(100-n) - \ln(100-n_{em})\right]^2 \right] + 0,01 \tag{9}$$

Where

$$b = \frac{\ln A_{em} - \ln \mu_0}{[\ln 100 - \ln(100-n_{em})]^2}; \tag{10}$$

$n$ – water content in oil in percent; $n_{em}$ – water content in oil, at which the viscosity reaches maximum value; $\mu_0$ – the viscosity of the anhydrous oil; $A_{em}$ – the maximum value of viscosity at $n=n_{em}$.

The experimental results show that the viscosity of the emulsion at a temperature of 20 °C and at water content from 10 % to 70% varies from 0,06 Pa·s to 0,15 Pa·s for the oil from Batyrbay region, from 0,011 Pa·s to 1,26 Pa·s for the oil from Tanyp region, and from 0,022 to 2,6 Pa·s for the oil from Kuzmin region.

The influence of temperature and water content on the viscosity of the emulsion is considered on the example of the Pioneer region. The results of experimental studies were processed in the form

$$\mu_{em,t} = \mu_t \cdot exp[\varphi \cdot a(t)] \tag{11}$$

and the following formulas are obtained:

$\mu_{em,20} = \mu_{20} \cdot exp(5,717\varphi)$ at $t=20$ ºC;

$\mu_{em,50} = \mu_{50} \cdot exp(4,865\varphi)$ at $t=50$ ºC;

$$\mu_{em}(\phi,t) = \exp\left[ \left(5,517\phi + \ln \mu_{20}\right)^{\frac{50-t}{30}} \left(4,865 + \ln \mu_{50}\right)^{\frac{t-20}{30}} \right] \tag{12}$$

where $\mu_{20}$, $\mu_{50}$ – dynamic viscosity of water-oil emulsion at a temperature of $t=20$ ºC and $t=50$ ºC, respectively; $\varphi$ - water content in emulsion.

For a specified oil at a water content of φ=0,2, the viscosity of emulsion at a temperature of t=20 °C equals to 709 *mPa·s*, and at t=60 ° C – 74 *mPa·s*. At φ=0,5 and t=20 ° C - 3399 *mPa·s*; t=60 ° C – 321 *mPa·s*.

It is noted that to evaluate the viscosity of water-oil emulsions with a ruined structure in the temperature range from 15 to 80 °C, the following formula can be used:

$$\frac{\ln \mu_{em,t}}{\ln \mu_{em,20}} = \left( \frac{\ln \mu_{em,50}}{\ln \mu_{em,20}} \right)^{\frac{t-20}{30}} \tag{13}$$

where $\mu_{em,t}$, $\mu_{em,20}$, $\mu_{em,50}$, – dynamic viscosity of water-oil emulsions with a ruined structure at temperatures of t=20 ºC and 50 ºC, respectively, *mPa·s*.

Scientists have studied the composition of the emulsifiers of oil and the emulsion structure of the environment to determine the technological parameters of oil dehydration and mechanism of the emulsion delamination (Gubaydullin, 2004). To match a composition of emulsifiers on stability of emulsion and the mechanism of separation, we have taken the samples from oil regions of Sangachaly-sea - Duvanny-sea, containing 10% paraffin and 0.1% of asphaltenes, and Umbaki region containing 80% resin and 4% asphaltenes (highly resinous oil). The viscosity of the paraffin oil (Duvanny-sea) at 10 °C was equal to 0.49 Pa·s, and the viscosity of resinous oil (Umbaki) – 0,4565 Pa·s.

Microscopic examination showed that the emulsions of highly resinous oil with a significant amount of asphaltenes (4 %) have different properties than the emulsions of paraffin oil, a different configuration of the globules distribution. Under identical conditions of water content (30 %) and the same consumption of de-emulsificator, the temperatures of samples are very different. Emulsions of resinous-paraffin oil are subjected to dehydration easier than emulsions of highly resinous oil with asphaltene content. Therefore, for example, at the consumption of emulsifier 0.004 g/t and at a sludge temperature of 50–55 ºC, water content for commercial paraffin oil amounts to 0.24 % and for commercial asphaltene-resinous oil at a temperature of 85-90 °C – 0.9% after a three-hour sludge.

To determine the viscosity of the emulsion within the changes of concentration of the internal phase from 0 to 0.5, the formula of Broughton and Squires is suggested (Ametov et al., 1985):

$$\mu = \mu_0 e^{k\varphi + c} \tag{14}$$

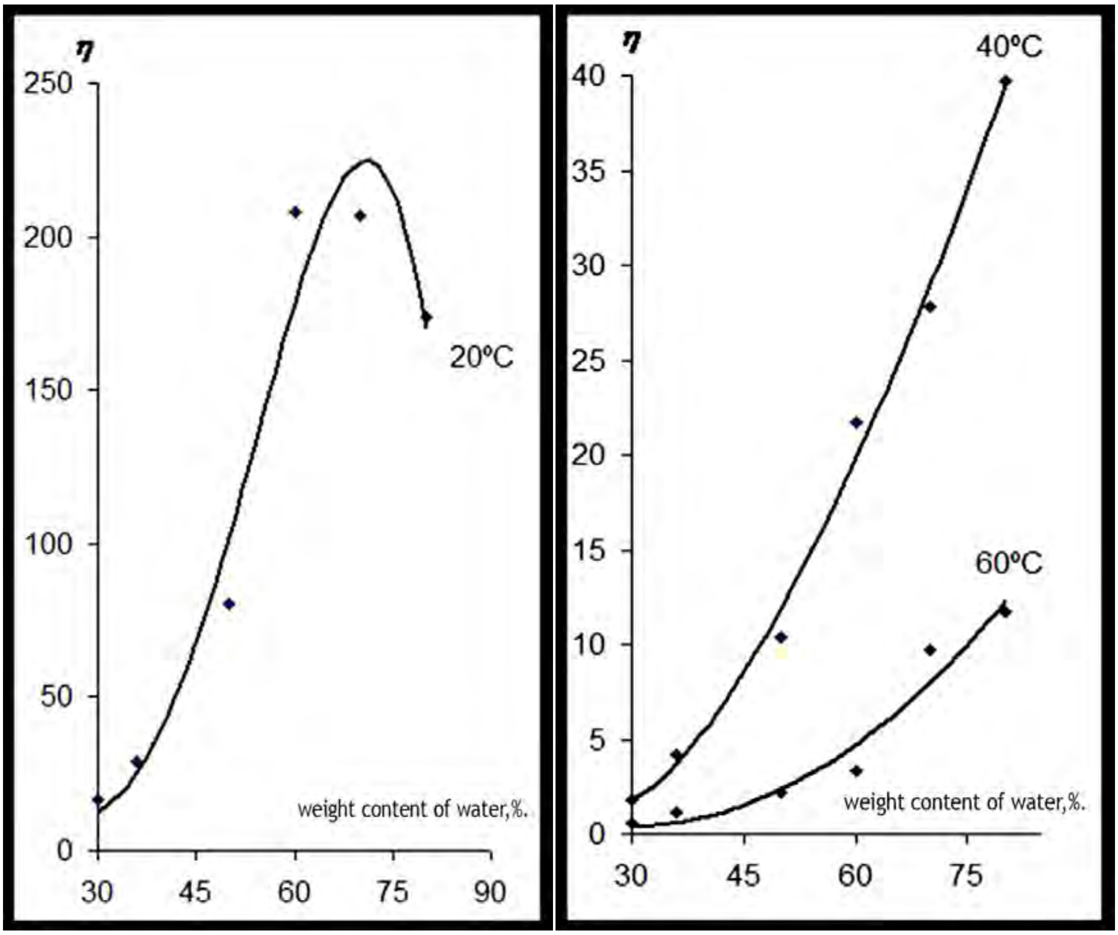
where $\mu$ - emulsion viscosity; $\mu_0$ – external phase viscosity; $\varphi$ - internal phase concentration; *k, c* – constants.

Viscosity of oil and oil-water emulsions is a key rheological parameter of practical importance in the production and design of pipelines. On the basis of the above experimental studies, we have conducted the calculation of the effective viscosity for North Buzachi oil region from the water content percentage.

Figure 1 shows graphs of the effective viscosity dependence of water-oil emulsions from the water percentage in them.

Analyzing the curves, we can conclude that for given temperature, the nature of the viscosity change is the same. With increasing water content, the viscosity increases, and then reaching a maximum, the viscosity steeply decreases. This decrease after the maximum value can be explained by the fact that the stability of inverse emulsions depends on the strength of the adsorption layers of natural emulsifiers in the oil. Currently, most researchers believe that the main stabilizers of emulsions of the type water-in-oil are colloid-dispersed in the form of micelles asphalten-resinous substances. Since the latter are contained in large amounts in the oils of the North Buzachi region and others, the greater stability of emulsions of these oils becomes clear.

The strength of adsorption layers depends on their thickness. The thickness of this layer, consisting of a condensed film of a surfactant, will decrease with increasing concentration of the dispersed phase. The critical thickness of the adsorption layer, obviously, corresponds to the maximum value, after which comes the treatment phase, i.e. there is a transition from the most compact packing of the dispersed phase particles at a given temperature to the concentration of the diluted direct emulsion. This explains the sharp drop in viscosity that occurs at the outstanding phases in the emulsions.




(a) (b)

**Figure 1: The dependence of oil emulsion effective viscosity**

(η in Pa·s) from the weight content of water at different temperatures (V=4 c-1): dots – calculated values; lines – approximating curves.

**Discussion and Conclusions**

Comparative analysis of emulsions formed by oils with a high content of paraffin and emulsions of highly resinous oils shows significant difference in viscous properties.

For example, a 20% emulsion of oil from Mangyshlak deposit at a temperature of 40 °C has a viscosity of 0.23 Pa·s, and oil from North Buzachi region under these conditions has the viscosity of 1.2 Pa·s, i.e. exceeds more than fivefold.

Note that in the process of collection and preparation of heavy oils, it is necessary to take into account the classification of oil according to its tendency to emulsificate. In addition, to reduce the viscosity of heavy oil-water emulsion, it is necessary to ensure the maximum possible temperature of the raw material. The experimental results show that in oils with a high content of asphaltene-resinous substances, this temperature is in the range of 60-80 °C.

Reducing the impact of produced salinity water requires prior collection of free reservoir water with the use of inhibitors to prevent scaling and corrosion (Tarasov et al., 2004). The main criterion of the dehydration with heating is the choice of optimal technological flow of the de-emulsificator. Experiments show that dosing above 300 g/t is not cost effective, as it dramatically increases operating costs.

Thus, optimization of technological modes of oil preparation in different periods of the deposit optimization with high-viscosity oil will be successfully resolved in the presence of evidence-based change patterns in structural and mechanical properties of oils and oil-water emulsions.

As a result of mathematical processing of experimental data, we obtained the formula for the dependence of the effective viscosity of water-oil emulsions on the volume content of water. If the water content is up to 0.55, it has the following form:

$$\eta = \eta_0 (1 + a\varphi + b\varphi^2 + c\varphi^3) \tag{15}$$

where $\eta_0$ - effective viscosity of anhydrous oil; φ – volumetric water content in water-oil emulsions; a, b, c coefficients determined using experimental data. Values *a*, *b* and *c* determined for the North Buzachi, Karazhanbas and Karaturun deposits at the emulsion temperature of 20°C, 40°C, 60°C and V=4 $c^{-1}$ are given in the Table 8.

Average square error in the calculations of the effective viscosity, is calculated according to the formula:

$$\delta = \sqrt{\frac{\sum_{i=1}^{n} \left( \frac{\eta_{ei} - \eta_{cali}}{\eta_{ei}} \right)^2}{n}} \tag{16}$$

within the limits of volumetric water content up to 0.5 do not exceed 4%. Here *n* is the number of experimental points; $\eta_{ei}$ and $\eta_{cali}$ – experimental and calculated by formula (15) values of the effective viscosity of the emulsion. Within the water content up to 0.6, this error increases to 12%. Apparently, this is due to the sharp increase in emulsion viscosity in the range of water content from 0.55 to 0.65.

**Table 9: Table of coefficients values in formula (15) at different temperatures**

| Deposit | Temperature, °C | Effective viscosity of anhydrous oil, η, Pa·s | Coefficients | | |
|---|---|---|---|---|---|
| | | | *a* | *b* | *c* |
| North Buzachi | 20 | 9,757 | 0,2342 | -22,8301 | 102,531 |
| | 40 | 0,806 | -9,0551 | 27,6513 | 76,2880 |
| | 60 | 0,226 | -1,8673 | 1,0398 | 74,0133 |
| Karazhanbas | 20 | 8,819 | 1,0918 | -28,7982 | 112,5850 |
| | 40 | 0,710 | -7,5070 | 16,0281 | 97,6902 |
| | 60 | 0,203 | -3,6108 | 7,3103 | 70,2463 |
| Karaturun | 20 | 9,221 | 1,4555 | -30,8676 | 114,9624 |
| | 40 | 0,760 | -8,7237 | 26,5526 | 78,7368 |
| | 60 | 0,211 | 0,7630 | -16,3839 | 103,4597 |

**Implications and Recommendations**

Thus, experimental studies helped to determine the regularities of the rheological characteristics changes of the oil deposits in the North Buzachi oil and gas region, depending on water content and temperature. The resulting formula allows calculation to determine the values of effective viscosity complex of oil-water emulsions based on this oil. It is established that with the increase of water content in oil and a decrease in shear rate, the viscosity of emulsions increases, which shows the increasing non-Newtonian behavior of the oil. The results show that oil-water emulsions in the oil of North Buzachi oil and gas region in certain proportions with water exhibit structural and mechanical properties even at high temperatures. For example, when water content in oil is from 22 to 36% and the temperature is up to 40 °C, the flow curves have properties of the power fluid, and at 60 °C – the degree of deviation from Newtonian behavior is low ($n \approx 0{,}96$). For water-oil emulsions with high water content (70 %), structural properties remain in the range from 20 °C to 60 °C.

To reduce viscosity of heavy oil-water emulsion (respectively, to ensure minimal cost of their transportation and processing), it is necessary to ensure the temperature in the range of 60-80 °C.

On the basis of the obtained results, the optimization of technological modes of oil preparation can be carried out in this field for further transportation and processing in the different periods of operation.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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