17th International Conference on "Energy and Climate Change"-11th Green Energy Investments Forum

(9-11 October 2024)

Scientific Sessions – Thursday 10.10.2024

10.30 – 10.50 **Assoc. Prof. Salim ASADOV (online)**

E.N. Aliev, R.Yu. Aliyarov, S.M. Asadov, H.Kh. Malikov

Application of SCF CO_2 to enhance oil recovery from reservoirs in a non-equilibrium state

Scientific Research Institute Geotechnological Problems of Oil, Gas and Chemistry. Azerbaijan State Oil and Industry University. 20 Azadlig Ave., Baku, AZ-1010 Azerbaijan

e-mail: r.aliyarov@asoiu.edu.az; h.malikov@gpogc.az

1 Introduction

Known technologies for oil displacement (flooding, thermal steam action, flow diversion, etc.) do not meet modern requirements. At the same time, the oil recovery factor (ORF) is low and amounts to more than 25%.

Therefore, the development of hard-to-recover oil reservoirs requires the development and application of new hydrocarbon production technologies. This will allow to increase the ORF and reduce the development time of the field. **Supercritical carbon dioxide (SC-CO_2)** displacement technology can be used in a wide range of thermobaric and physicochemical conditions in the reservoir.

In practice, oil recovery enhancement methods are divided into two groups:

1) Methods of oil production intensification (MOPI);
2) Methods of enhanced oil recovery (MEOR).

In MOPI includes technologies that increase the flow of fluid to the bottom of the production well.

In MEOR methods they influence the development object or part of it, and include residual, unrecovered oil reservoirs in the development.

Thus, the use of unique properties of solvents in a supercritical state allows to increase the efficiency of the technology of extraction of hard-to-recover oils.

The study of thermobaric regularities of the systems "heavy oil– supercritical solvent" allows to create new highly effective methods of intensification of extraction of high-viscosity oils.

The obtained data on supercritical extraction in oil refining and petrochemistry are necessary for control and purification of the environment.

Therefore, the development of new, environmentally friendly and energy-saving technologies for oil production and processing is an urgent task.

One of the methods of increasing oil recovery is the displacement of oil using high-pressure CO_2.

The purpose of this work is to determine the patterns of change in volumetric and phase behavior, as well as to increase the oil recovery of **high-viscosity oil when interacting with SC-CO_2.**

2 Methodological Part

The main properties of the used oil reservoir on average were the following: density of reservoir oil at reservoir pressure 963 kg/m^3, viscosity at reservoir pressure 795–802 mPa·s, concentration (weight %) of paraffin 1.9, resins 49.3, asphaltenes 9.3, water 2.8, mechanical impurities 0.007.

The composition of oil reservoir consisted of C9+ residue (95%) and lighter hydrocarbons.

PVT analysis of oil samples was carried out using a PVT 3000-L installation . Laboratory studies of the interaction of SC-CO_2 with high-viscosity oil were carried out in the following optimal thermobaric ranges: 300–305 K and 7–7.5 MPa.

The solubility of supercritical carbon dioxide in heavy oil was studied in the temperatures of 300–305 K and pressure range of 7.2–7.5 MPa. The error in determining solubility was < 1.5%.

The PVT installation diagram is shown in Figure 1.

A mixture of oil and SC-CO_2 was placed in pump cell1. SC-CO_2 was pumped into auxiliary cell 2. Mixing of the components of the “heavy oil–SC-CO_2” system occurred with valves V6 and V2 open and the pump and auxiliary cells operating in pumping mode.

The concentration of SC-CO_2 in the mixture was monitored via volumetric method. Thus, the process of one-time mixing of the components was reproduced.

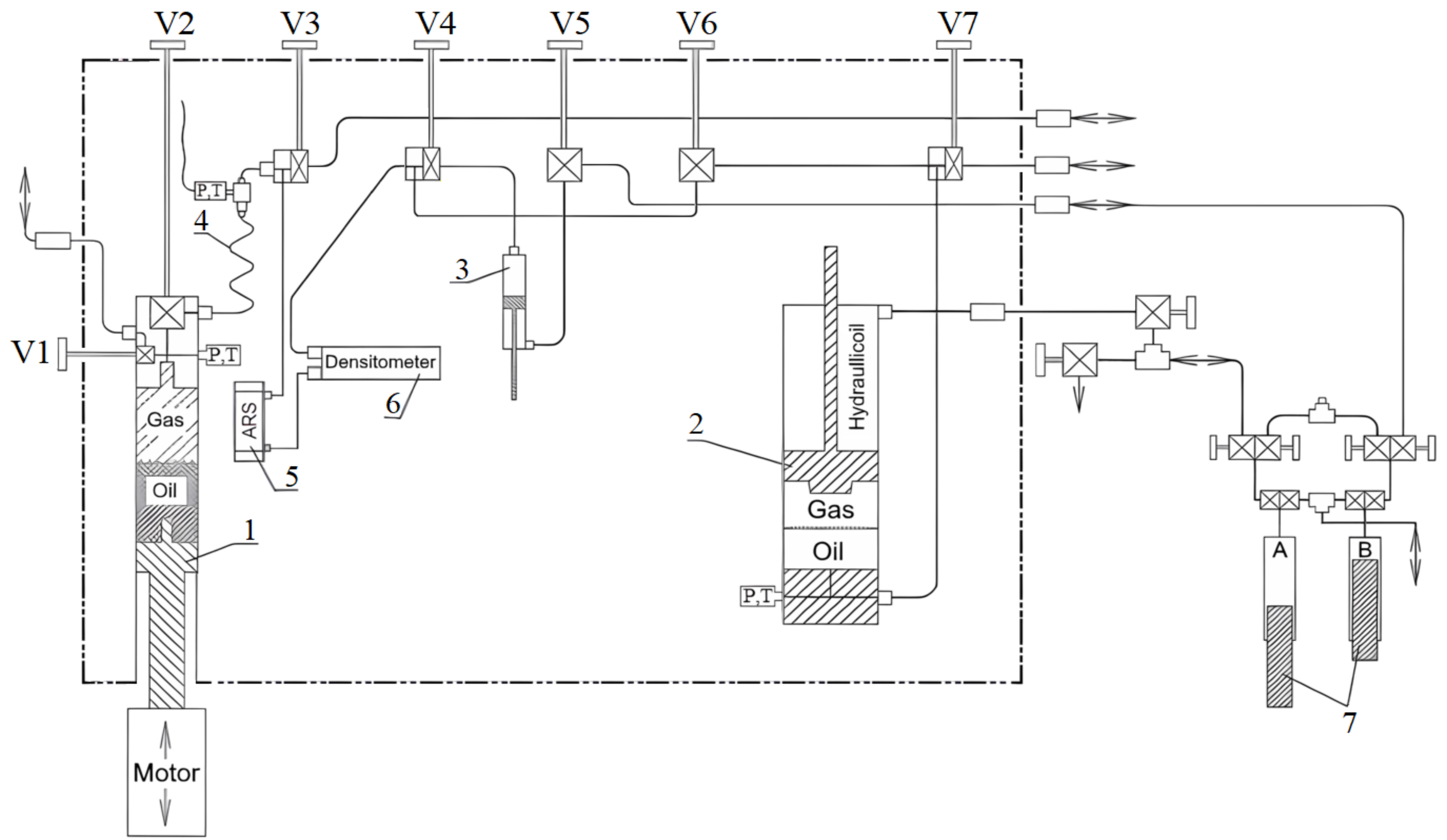


Figure 1. Installation diagram of *PVT* 3000-L: V1–V7 – needle valves; 1 – pump cell; 2 – auxiliary cell with a piston; 3 – minicell; 4 – capillary viscometer; 5 – ultrasonic solid phase registration system; 6 – digital density meter; 7 – dual cylinder digital pump.

Experiments on oil displacement by carbon dioxide fluid were conducted on a laboratory setup, the scheme of which is shown in Figure 2.

PV measurements were conducted under isothermal conditions with a decrease in oil system pressure.

The saturation pressure, relative volume, density, compressibility coefficient and specific volume of the oil system were determined. The saturation pressure is determined by the characteristic break in the PV phase isotherms.

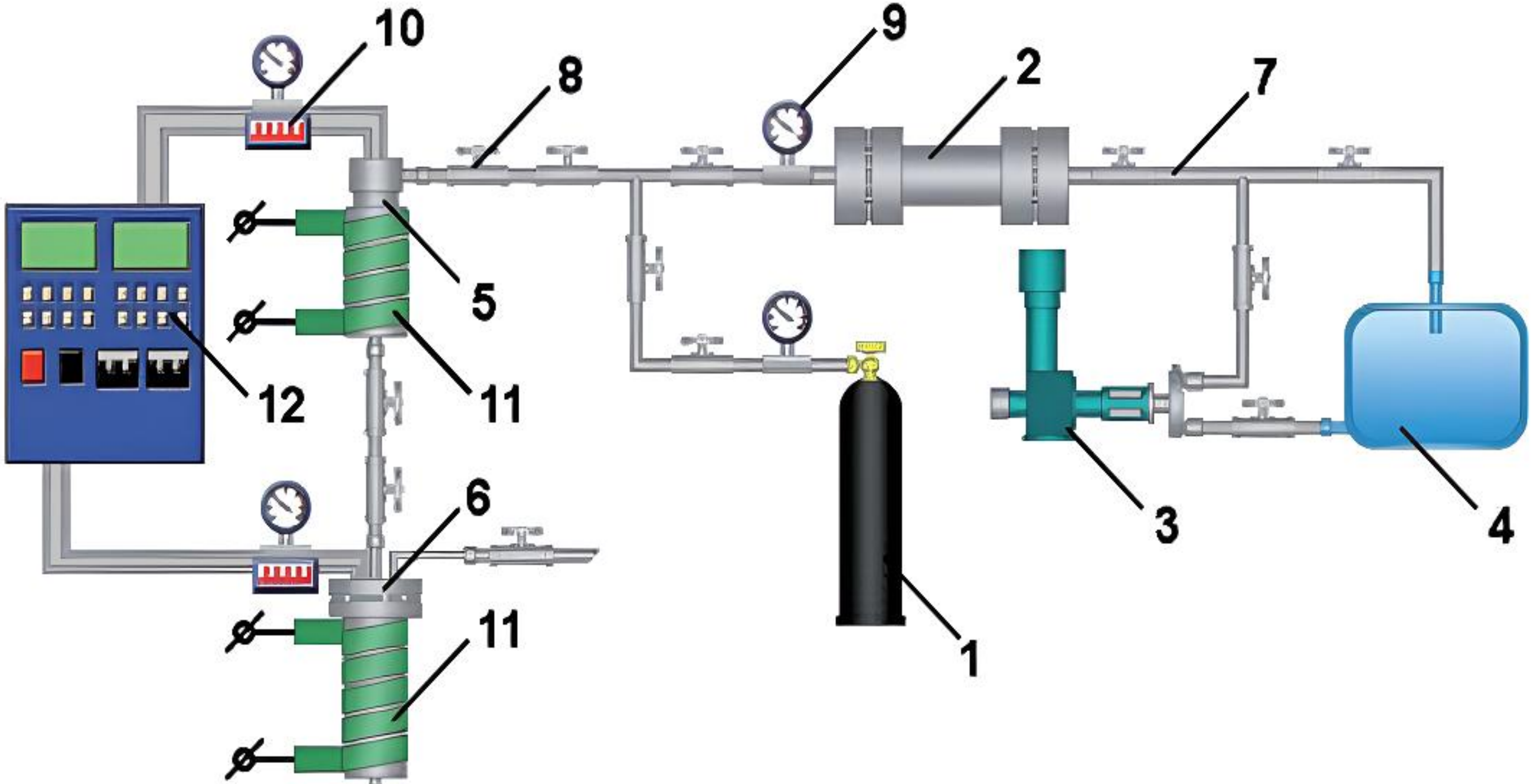


Figure 2. Scheme of the experimental stand for hydrocarbon extraction using supercritical fluid extraction: 1 – container with CO_2 gas; 2 – high pressure cylinder with piston; 3 – high pressure water pump; 4 – water container; 5 – extractor; 6 – separator; 7 – pipeline; 8 – shut-off valves; 9 – pressure sensor; 10 – temperature sensor; 11 – heater; 12 – automation unit.

CO_2 gas from a source (cylinder) is fed to the PVT device (**Fig. 2)** and there it is compressed into a supercritical fluid at the critical point (7.38 MPa and 304.1 K).

Then the SC-CO_2 is pumped into the pipeline of the unit simulating a model of the system of hard-to-recover heavy oil containing SC-CO_2.

In such a system, CO_2 remained in the form of a supercritical fluid.

3 Results and Discussion

The data obtained using supercritical fluid technology in heavy oil–SC-CO_2 systems are important for the development of environmentally friendly oil production and refining industries.

Taking into account the above methods, we will consider the patterns of change in volume and phase behavior of high-viscosity oil when interacting with SC-CO_2 that we have obtained.

The dependences of CO_2 solubility on temperature (pressure) at different pressures (temperatures) in the studied heavy oil samples differed from each other.

CO_2 solubility decreased monotonically depending on temperature at different pressures. The experimental results are presented in Figure 3.

Near reservoir conditions, the temperature and pressure dependences of CO_2 solubility for different heavy oil samples differed little from each other.

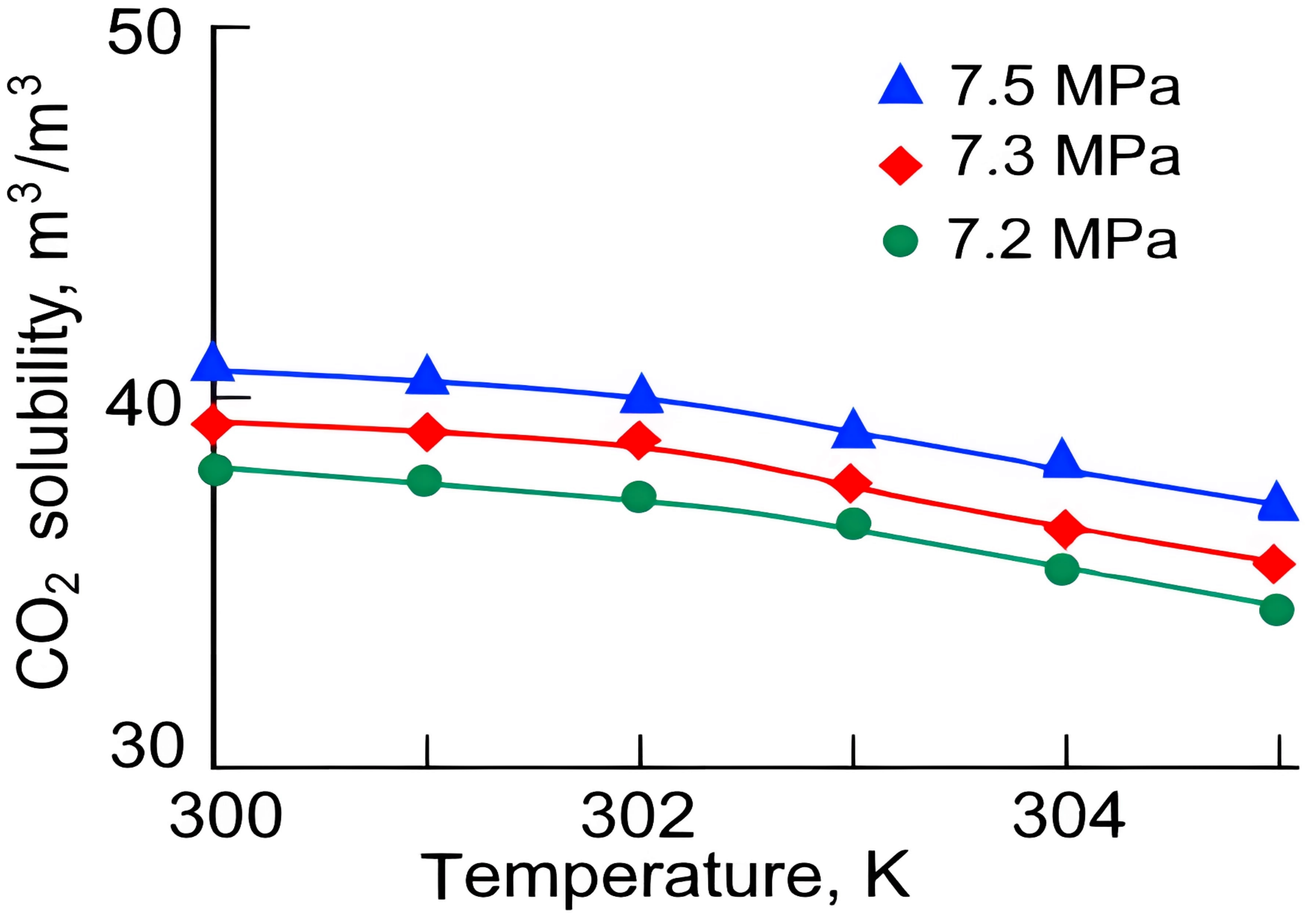


Figure 3. Dependence of CO_2 solubility on temperature at 7.2–7.5 MPa in heavy oil.

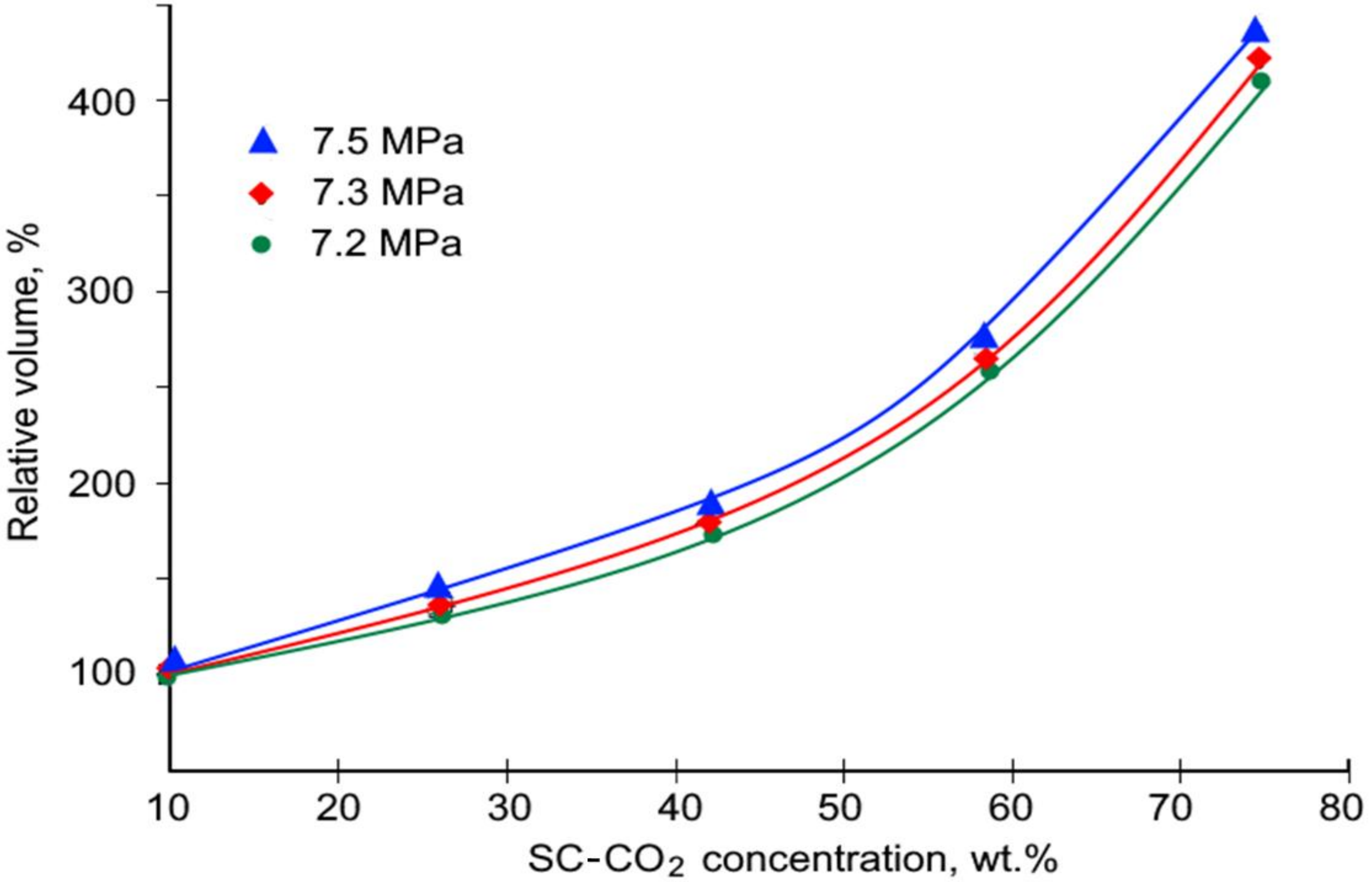
CO_2 has the following critical point: (T_{cr} = 304.1 K) critical temperature and (P_{cr} = 7.38 MPa) critical pressure.

Increasing the critical pressure of CO_2 above 7.5 MPa does not significantly affect the dissolving properties of SC-CO_2 in the heavy oil–SC-CO_2 system.

Based on this, the experimental results were obtained at 7.2–7.5 MPa and 303–313 K.

The viscosity of the oil samples was 800 mPa·s, the permeability of formation was 0.2 μm^2.

Figure 4. The dependence of the ratios of the volumes of oil mixtures on the concentration of SC-CO_2 (10-75 wt.%) at 303 K.



The distribution of the system volume relative to the volume of the original oil at 7.2 MPa is shown in Figure 5.

The lines of two-phase equilibrium “heavy phase” and “light phase” characterize the corresponding contributions of the phases to the increase in the volume of the system.

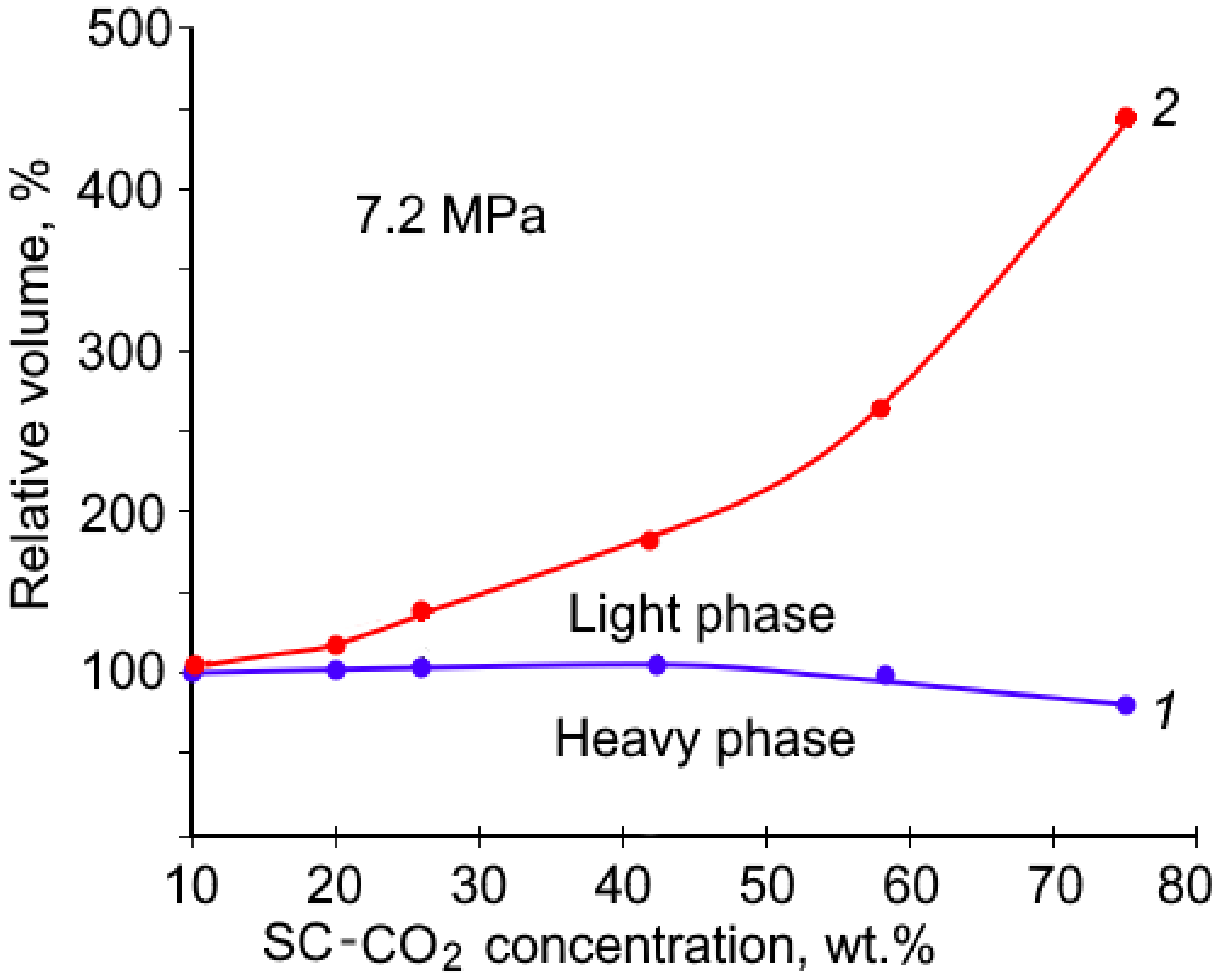


Figure 5. Dependence of the ratios of the volumes of oil mixtures on the concentration of SC-CO_2 in the “heavy oil–SC-CO_2” system at 303 K.

Light components of the oil system are intensively extracted already at a concentration of SC-CO_2 of 20 wt.%. In this case, relative to the total volume of the oil system, the volume of the heavy phase decreases slightly with an increase in the concentration of SC-CO_2 from 10 to 75 wt.% (Figure 5).

Thus, the concentration of SC-CO_2 20 wt.% in the "**heavy oil**–SC-CO_2" system is optimal, at which heat and mass transfer processes between phases lead to swelling of oil.

In such a system, which does not contain a volumetric heat source, heat transfer can be described by the heat convection-diffusion equation (1): where c is the specific heat capacity, t is the time, ρ is the density, v_f is the kinematic viscosity of the fluid phase, D is the heat diffusion tensor of the corresponding component of the system, T is the temperature.

$$\frac{\partial(c_p T)}{\partial t} = -\nabla(c_f \rho_f v_f T) + \nabla(D \nabla T) \quad (1)$$

Figure 6. The isobaric dependence of the viscosity of the heavy phase of the system on the concentration of SC-CO_2 at 303 K.

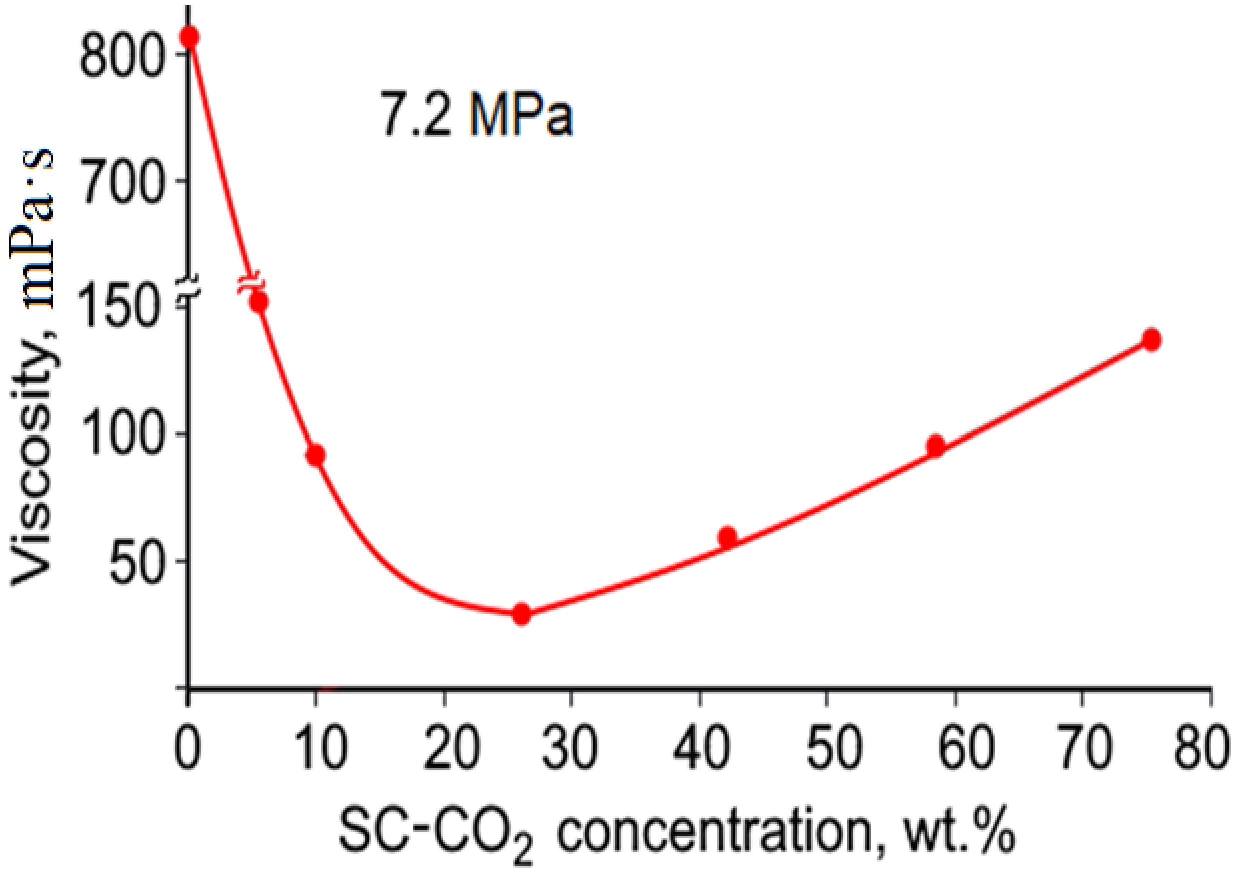
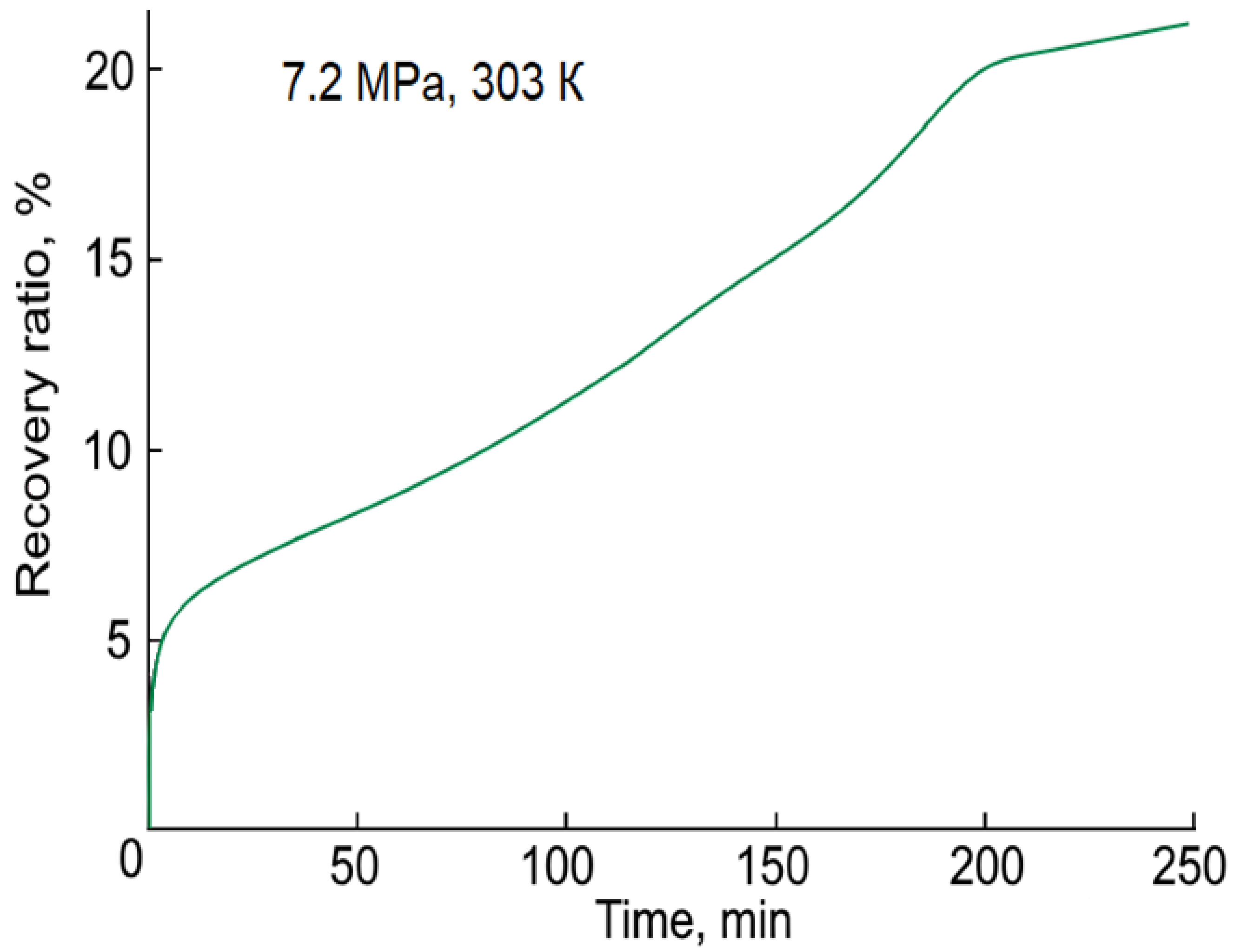


Figure 7. Time dependence of oil recovery during a single displacement of oil by SC-CO_2 fluid at 7.2 MPa and 303 K.



When injecting SC-CO_2 with 10–15 wt.% into the system, the degree of oil recovery was low and amounted to about 8% in 10 min.

When injecting SC-CO_2 with a concentration of 20 wt.%, oil recovery increases and amounted to 11% during this time.
With an increase in the interaction time of SC-CO_2 with oil in the range of 50–200 min, the degree of oil recovery increases.

As can be seen from Figure 7, when SC-CO_2 interacted with oil for more than 200 min, the average degree of oil recovery was about 23%.

CONCLUSIONS

Studies of the behavior of heavy oil phases during interaction with SC-CO_2 under reservoir conditions have shown the following.

1 The parameters of change in PVT properties of fluids during fluid injection into the "heavy oil–SC-CO_2" system determine the characteristics of displacement and extraction of heavy oil.

2 The volume of the heavy hydrocarbon phase relative to the volume of the "heavy oil–SC-CO_2" system decreases almost linearly with increasing SC-CO_2 concentration (20 wt.%)

3 Addition of $SC\text{-}CO_2$ to the "heavy oil-$SC\text{-}CO_2$" system sharply reduces the pressure in the flow from 7.5 to 7.2 MPa. Such a pressure drop increases the efficiency of oil displacement and intensifies the oil recovery process due to an increase in viscous forces in the reservoir model system.

4 The average degree of extraction of heavy oil components when pumping $SC\text{-}CO_2$ into a high-viscosity oil system was 23% in 250 min.

5 The results obtained can be used in the design of environmentally friendly development of oil fields and the production of hard-to-recover oils, as well as for the intensification of oilfield equipment for the development of high-viscosity hydrocarbons.

Thank you for your attention!