Experimental study of two-phase filtration regimes of methane–n-pentane mixture

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Abstract. The results of experimental studies of methane–n-pentane mixture filtration in a porous medium under isothermal conditions in pressure range typical for gas-condensate reservoirs are presented. Interest in the filtration problem of such mixtures is aroused by the need to intensify production of heavy fractions of gas-condensate–valuable hydrocarbons, consisting of methane and its higher homologues. Different flow regimes including oscillatory one are observed during gas-condensate extraction under natural conditions. Our studies have shown that there are multiple flow regimes including self-oscillating one under isothermal conditions for this type of mixtures depending on the initial pressure, the kind of the mixture's phase diagram and the permeability coefficients of the liquid and gas phases in the porous medium.

1. Introduction

The processes of multiphase filtration in porous media are widely distributed while developing hydrocarbon reservoirs of various types. This type of flow occurs in both cases of the feedstock extraction (gas hydrates, gas-condensate) and various processes aimed to increase the debit (steam and surfactants injection into the formation). Capillary forces play an essential role in such processes: they regulate the mutual distribution of the phases in the pore medium, determine the transfer conditions and the values of interfacial surfaces. Generally, the existing approaches allow to describe the transport processes in porous media strictly enough just for individual pores or for the simplest form of capillary system [1]. The development of methods of mathematical and physical simulation of such processes is required to describe the multiphase multicomponent filtration adequately.

This paper concentrates on the experimental studies of the methane–n-pentane binary mixture filtration in the porous medium. The mixture serves as a model one of gas-condensate fluid. Interest in the filtration of such mixtures is aroused by the need to intensify the process of gas-condensate extraction–valuable hydrocarbons, consisting of methane and its higher homologues. The light fraction can be extracted almost completely while developing the field of this type, but condensate recovery factor of the fraction C_{5+} is less than 30% [2].

There are different flow regimes, including oscillatory one [3], while gas-condensate production under natural conditions. The presence of the oscillations under particular boundary conditions is confirmed by the laboratory research of model mixtures of these fluids [4, 5]. There is no generally accepted confirmed explanation of the such oscillation occurrence. Non-equilibrium of phase transitions in the porous medium, hysteresis of relative phase permeabilities, the difference


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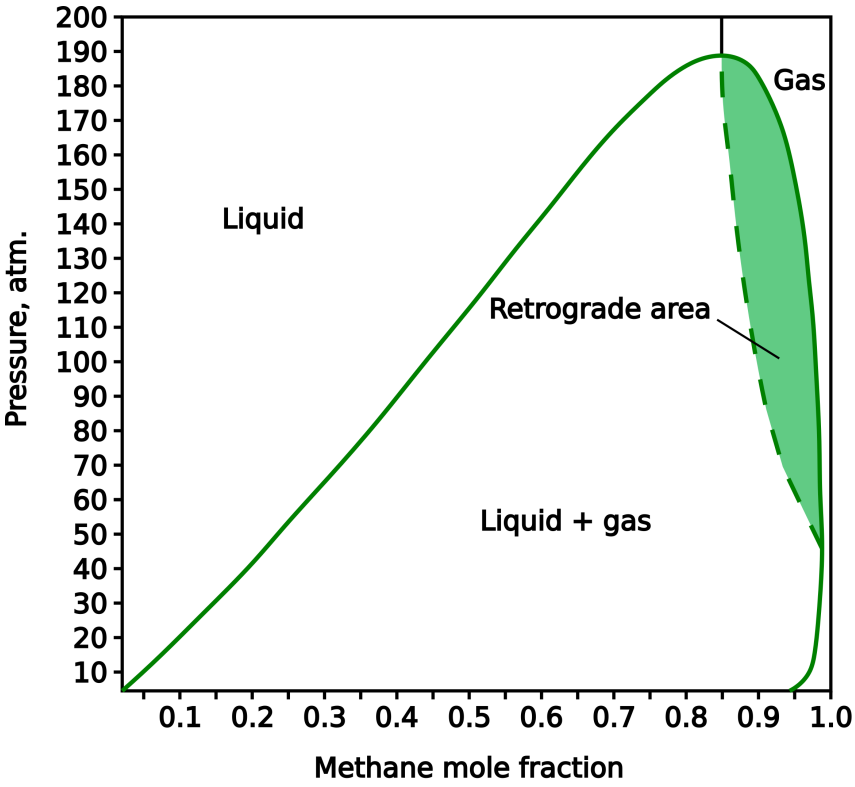


Figure 1. Phase diagram of methane–n-pentane mixture.

between mixture component phase states in free space and in the pores of host medium werethe possible causes [6]. In this paper the existence of different filtration regimes of hydrocarbon mixtures is explained by the features of the phase diagrams of such mixtures–the presence of retrograde areas of evaporation and condensation (figure 1) and by the difference of relative phase permeabilities of porous medium for gas and liquid.

2. The statement of the problem

Various filtration regimes have been obtained while conducting previous studies with model mixtures of methane–n-butane and methane–propane–n-butane [4]. Although investigated mixtures have retrograde properties, there is an essential fault of their usage–all their components could be extracted while producting of the real reservoir almost entirely (being a part of lean gas) in contrast to the fraction C_{5+}, which has liquid form under thermo-baric conditions of well bottom area. Thus, these mixtures simulated real gas-condensate fluids incompletely.

Methane–n-pentane mixture acted as a model one in this study. Mole fraction of methane and n-pentane equaled 85% and 15% correspondingly. This mixture was chosen based on the following considerations:

(i) Mixture composition should be typical for real gas-condensate fluids: 70–90 mole percentage of methane and 10–30 mole percentage heavy fraction C_{5+};

(ii) Easy availability to the components of the model mixture;

(iii) The phase state of mixture components under normal conditions–one of them is in the gas form, another is in the liquid one;

(iv) The presence of retrograde regions in the phase diagram of the model mixture;

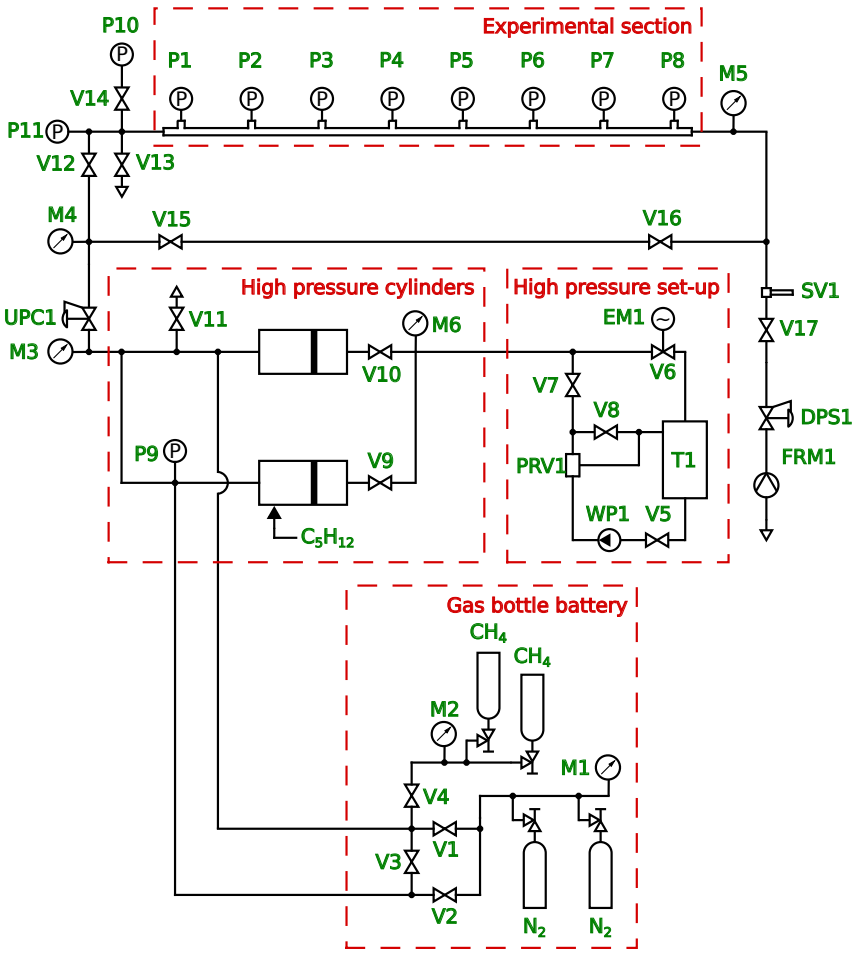


Figure 2. Layout of experimental set-up "Plast": P1–P11—pressure sensor; M1–M5—manometers; V1–V19—valves; SV1—sample vessel; UPC1—downstream pressure controller; DPC1—upstream pressure controller'; EM1—electric motor; T1—water tank; WP1—pump; PRV1—pressure-release valve; FRM1—flow rate meter; CH_4—methane bottle; N_2—nitrogen bottle.

(v) The capability to achieve supercritical parameters for the model mixture on experimental set-up.

The purpose of this experimental study was to obtain various filtration regimes of model hydrocarbon mixture (gas regime, gas–liquid one and oscillatory one).

3. Experimental set-up

Experimental set-up "Plast" (figure 2) is served for laboratory research of gas-condensate mixture flow regimes. This machine allows you to simulate one-dimensional filtration process of hydrocarbon mixtures under natural thermo-baric conditions [7]. Configuration of the set-up make it possible to vary the pressure of the model mixture in the range 0.1–28 MPa and the temperature in the range 283–473 K.

The set-up consist of the following components:

(i) Gas bottle battery;

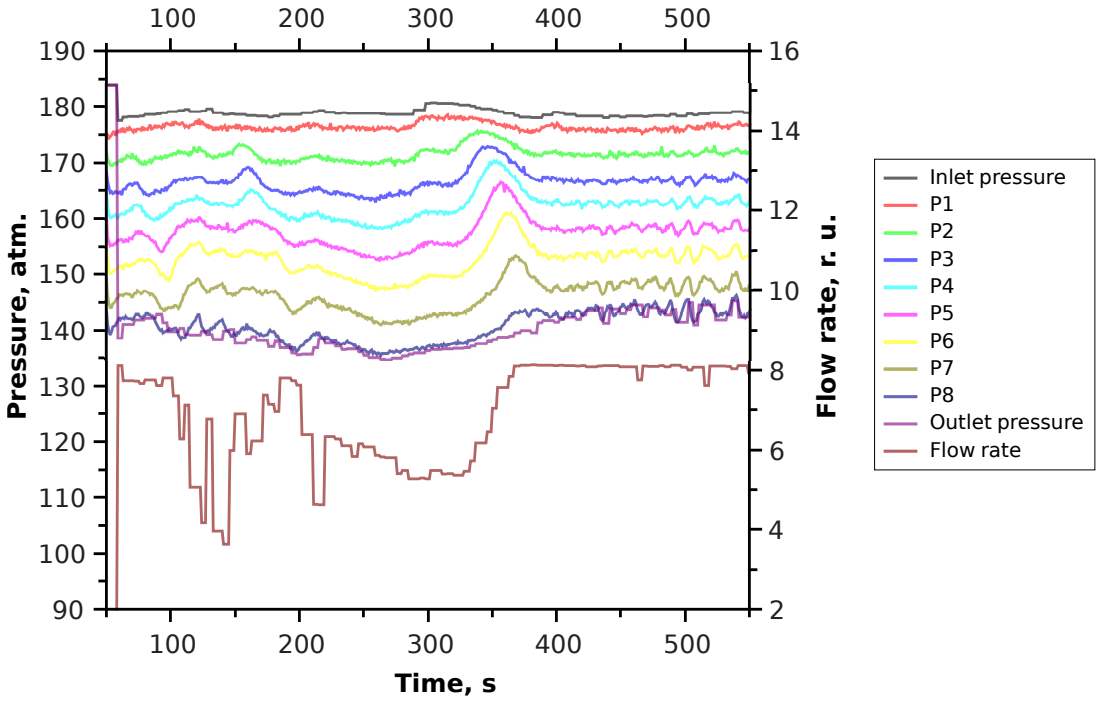


Figure 3. Time-dependences of flow rate at the outlet of the ES and pressure distribution along the ES.

(ii) High-pressure set-up;
(iii) High-pressure cylinders;
(iv) Experimental section (ES);
(v) Information-gathering system.

The experimental section (ES) is made of a stainless steel pipe filled with quartz sand (fraction 0.09–0.125 mm). It is 3 m long and its internal diameter is 10 mm. There are 8 pressure sensors mounted along the pipe on distance 40 cm apart.

4. Results

Model binary mixture of the required composition (mole fraction of methane is 85%, mole fraction of pentane is 15%) was prepared in high-pressure cylinders. Then, the pressure in the cylinders was increased to supercritical for the model mixture (P_{cyl} = 21 MPa) in order to transfer the mixture to single-phase state. Predetermined pressure drop on the ES was installed by pressure controllers at the inlet of the ES (P_{inlet} = 18.5 MPa) and at the outlet of it. Then, the mixture started to inflow into the ES and cylinder pressure was maintained at the preset value P_{cyl} = 21 MPa.

It is possible to obtain various filtration regimes with different values of the pressure at the inlet of the ES and at the outlet of it. For example, a single-phase flow regime (gas regime) with constant flow rate and uniform pressure distribution could appear if the pressure along the ES will not drop below the critical value.

Figure 3 displays gas–liquid regime in which liquid and gas phases flow together. Flow rate oscillations due to retrograde condensate appearance in the porous medium of the SE take place in the time interval from 100 s to 370 s. Liquid phase permeability is much lower then gas one,

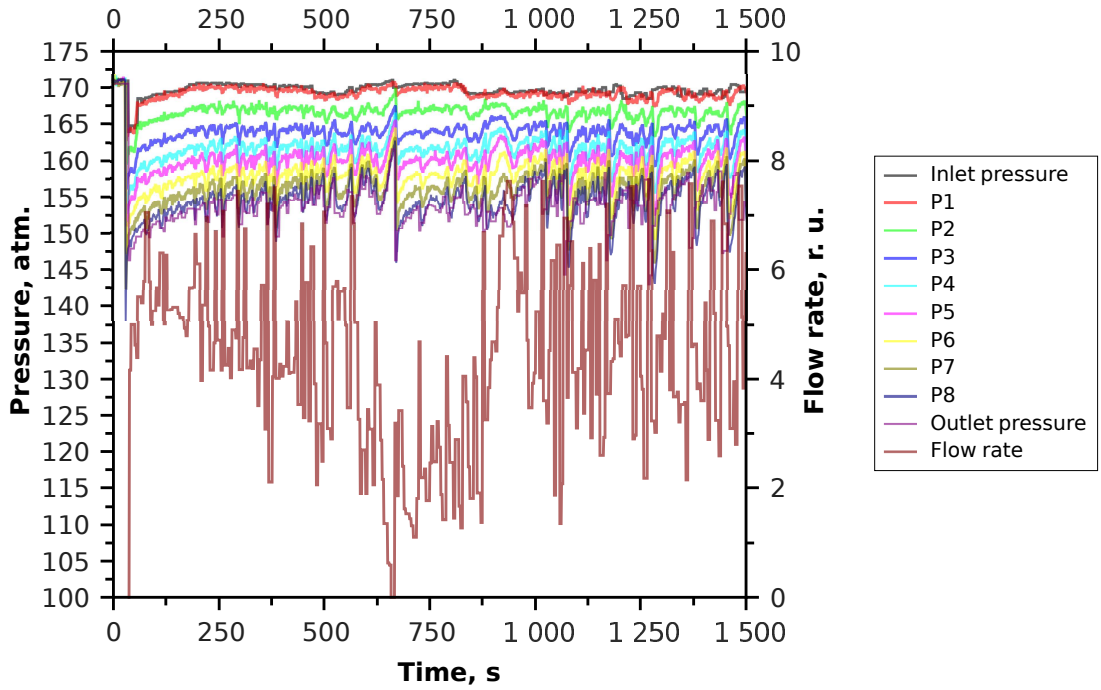


Figure 4. Time-dependences of flow rate at the outlet of the ES and pressure distribution along the ES.

but the pressure drop is large enough to drive both phases from the porous space, so steady-state regime could be observed after 370 s.

Oscillatory filtration regime is shown in figure 4. Pressure drop in not enough to drive the formed liquid in this case, therefore it is possible to observe oscillation occurrence of flow rate at the outlet of the ES and pressure towards the outlet of the ES. Pressure oscillations gain in magnitude along the ES and reach their maximum at the outlet of ES due to increasing difference between the current pressure and the critical one (i.e. stronger retrograde properties). Flow rate oscillations are 1.5 times greater than oscillations in the case of gas–liquid regime.

5. Conclusions

Experimental studies of various filtration regimes of methane–n-pentane binary mixture have been conducted. Physical simulation has shown the presence of oscillatory flow regime for this model mixture which was predicted by mathematical model created previously [4].

Two two-phase filtration regimes have been obtained: gas–liquid regime and oscillatory one. For the experimental conditions of this study (the composition of the mixture model, the inner diameter and the length of the experimental section, the inlet pressure) the pressure drop of 40 bar provides gas–liquid filtration regime, the pressure drop of 20 bar causes oscillatory filtration regime.

Acknowledgments

This work was supported by the Russian Science Foundation (project No. 14-50-00124).

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