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AN EXPERIMENTAL INVESTIGATION OF THE EFFECT OF FORMATION AND DESTRUCTION OF A CONDENSATE PLUG IN A ONE-DIMENSIONAL MODEL OF GAS-CONDENSATE STRATUM

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ABSTRACT

An experimental investigation is performed of the effect of formation and destruction of a condensate plug under conditions of filtration of a binary mixture of hydrocarbons (methane–n-butane) in a one-dimensional model of gas-condensate stratum. An experimental investigation is performed of the thermal effect on the condensate plug formed. It has been demonstrated that the temperature increase to 340 K results in the recovery of the flow rate of mixture and of the concentration of components.

INTRODUCTION

Gas condensate is a complex mixture of methane and higher derivatives of the methane series. The phase diagram of such a mixture contains the so-called “retrograde region”, i.e., a region in which a pressure decrease may cause the formation of retrograde liquid evaporating with further pressure decrease. The extraction of condensate from the productive stratum is accompanied by a pressure drop and variation of temperature in the vicinity of the well bottom. The gas-condensate mixture in the bottom-hole formation zone partly condenses with the formation of retrograde liquid which fills the pore space and prevents the gas phase from flowing out. The filtration of a multicomponent two-phase mixture toward the well bottom causes an increase in the saturation of pore space with condensate compared to the process of differential static condensation up to the formation of a “condensate plug”. This further causes the deterioration of quality of produced stock: the most valuable part of the latter is concentrated in the hard to extract liquid fraction [1].

It is the objective of the present study to perform experimental and theoretical investigation of the effects of formation and destruction of gas condensate plug.

NOMENCLATURE

P	Pressure
T	Temperature

EXPERIMENTAL FACILITY

The physical simulation of methods of stimulation of gas-condensate plug was performed in the Plast experimental test bed developed at the Joint Institute for High Temperatures of the Russian Academy of Sciences. The test bed is designed for the investigation of the processes of filtration of formation fluids under the thermobaric conditions of real strata. The parameters, which the facility is capable of providing (pressure P up to 40 MPa and temperature T up to 400 °C), make possible wide range simulation of formation conditions and experiments with liquids and gases of different fractional compositions.

Gas condensate was simulated by a methane–n-butane binary mixture, the phase diagram of which contains a retrograde region in temperature and pressure ranges close to the thermobaric conditions of real gas-condensate strata (P = 10–12 MPa, T = 290–350 K). The block diagram of the Plast test bed is given in Figure 1.

The one-dimensional model of stratum was provided by a thermostatically controlled pipe of Kh18N10T (chrome-nickel-titanium) stainless steel 2.2 m long with an inside diameter of 10 mm filled with pre-washed quartz sand with a fraction of 0.09–0.125 mm.

The methane–n-butane mixture was prepared in a high-pressure cylinder at a pressure of 13 MPa, with the mass concentration of methane for different experiments being 45% on the average, and that of n-butane–55%. T

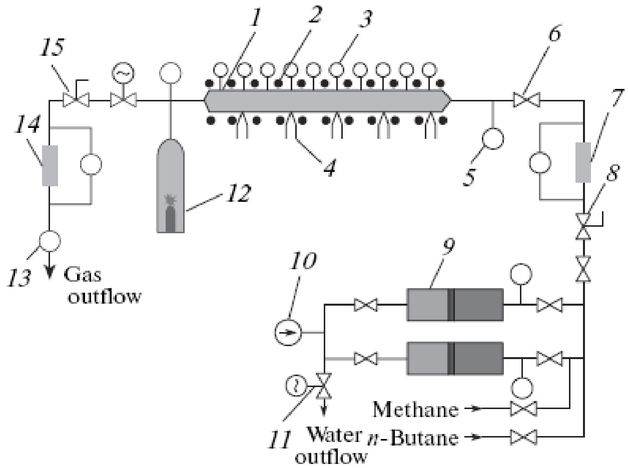

Figure 1 Block diagram of the Plast test bed: (1) experimental section; (2) heater, (3) strain gages, (4) thermocouples, (5) pressure cells, (6) valve, (7) flowmeter, (8) reducer, (9) separation cylinder, (10) proportioning pump, (11) electrically driven valve, (12) gasdynamic pipe, (13) gas meter, (14) flowmeter, (15) pressure regulator.

he temperature of thermostatic control was varied from 290 to 350 K. These parameters provide for the mixture to be in the retrograde region of phase diagram during the experiment. The measured permeability coefficient of the experimental section (ES) was $3.8 \cdot 10^{-11}$ m^2.

A constant pressure difference was maintained throughout the experiment in the ES after it was filled with the mixture at a pressure of 12 MPa. The pressure at the inlet was 10–12 MPa for different experiments, and that at the outlet–9-5 MPa. The gas phase flow rate at the outlet from the ES, the temperature of the incoming and outgoing mixture, the temperature in the thermostat, and the pressure in the mains of the facility were measured in the experiments. Sampling was made for the purpose of chromatographic analysis of the composition of initial mixture and of the composition of mixture at the outlet from the ES during the experiment. For automating the measurements and monitoring the parameters of the experiment, the data were outputted to a controller.

The possibility of experimentally producing a gas-condensate plug was studied in the first stage of physical simulation of the process of filtration of gas-condensate mixture. The mixture pressure at the ES inlet corresponded to the supercritical region of phase diagram, and that at the outlet–to the retrograde zone. The composition of the mixture was selected so as to provide for the maximal condensation effect at the selected temperature of the thermostat. If a condensate plug is formed in the process of filtration through the ES, the condensate flow rate at a constant pressure difference decreases, and the composition of the gas phase of mixture at the ES outlet shifts toward increasing concentration of the more volatile component, i.e., methane.

In the second stage of the experiment after the formation of gas-condensate plug, the model section was subjected to thermal stimulation: the temperature either of the thermostat or of the incoming mixture was raised by heating the pipeline segment before the ES inlet. In the former case, the heating of the stratum as a whole by an external heater is simulated, and in the latter case–the heating by hot condensate.

The thermal stimulation of the stratum causes a variation of the conditions of phase equilibrium, and a part of high-boiling hydrocarbons make the liquid-to-gas phase transition. In addition to the rise of concentration of high-boiling component in the gas phase, the phase permeability increases. As a result, the composition and flow rate of the model mixture after thermal stimulation return to their initial values. Therefore, under real field conditions, one can expect the condensate recovery factor to increase with the temperature of gas-condensate.

RESULTS

The initial pressure of the mixture in experiments in physical simulation of the process of filtration of gas-condensate mixture was 12 MPa; this corresponds to the supercritical region of the phase diagram of model mixture for all investigated values of mass concentration (45–60% methane) and temperature of 290–350 K. The pressure difference in the experimental section in different experiments was varied from 3 to 8 MPa. This variation of parameters made possible the investigation of the most typical regions of the phase diagram of model mixture. The experiments revealed that no gas-condensate plug is formed in the investigated range of temperatures and pressures with the initial mass concentration of methane of higher than 60%. Neither does the plug form at the mass concentration of methane of 45% and T = 340 K.

The experiments under conditions corresponding to the retrograde region of phase diagram (methane concentration of 43–50%, temperature of the mixture up to 310 K) revealed the formation of condensate plug during periods of time the duration of which depends on the pressure difference in the experimental section.

A series of experiments were performed for the purpose of investigating the thermal effect on the condensate plug formed.

The initial mass concentration of n-butane was 57% and that of methane–43%, the pressure difference in the experimental section was maintained constant and equal to 4 MPa, and the thermostat temperature was 290 K. The mixture flow rate was $1.2 \cdot 10^{-3} m^3/s$.

Following the formation of condensate plug, the mixture flow rate decreased to $0.8 \cdot 10^{-3}$ m^3/s and the butane concentration–to 25%. Then the thermostat temperature was raised to 340 K. The mixture flow rate and the concentration of components recovered their initial values 150 s after the heater was switched on.

The experimentally obtained time dependence of the gas phase flow rate at the outlet from the experimental section and the result of calculation of the process of plug formation using the PLAST computer codes [2] are given in Figure 2.

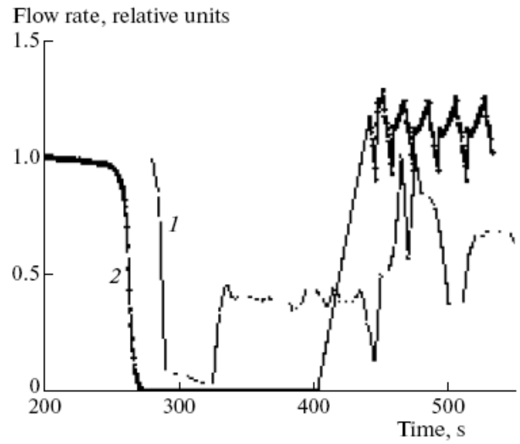

Figure 2 The time dependence of relative flow rate of the mixture under conditions of increasing temperature of the thermostat: (1) experiment, (2) calculation.

The calculated and experimentally obtained values of time of plug formation and of concentration of components in the gas phase at the outlet from the experimental section agree within the experimental error. The difference in the behavior of experimental and numerical data after the instant of plug formation is due to the fact that the experimental model may exhibit nonuniformities of the temperature and properties of the pore space along the pipe radius. Such nonuniformities may cause internal flows of liquid in the experimental section. As a result, the flow rate of mixture abruptly decreases but does not cease completely.

The periodic variation of the flow rate after the process becomes steady-state at a temperature of 340 K (curve 2) is caused by the advance of the thus formed liquid phase under the effect of pressure difference in the experimental section. The condensate plug forms in some region of the experimental section as a result of two processes, namely, the differential condensation of mixture and the filtration into this region of the liquid condensed in the neighboring regions. If the rate of formation of plug is higher than the rate of its advance toward the end of experimental section, the mixture ceases flowing out. Otherwise, the condensed liquid reaches the exit cross section of the experimental section, and the mixture flow rate is partly recovered. According to the calculations, the period of this process is 30–40 s, which coincides with the experimentally measured period of fluctuations of the flow rate at the outlet of the experimental section.

The subsequent series of experiments involved the monitoring of the temperature of mixture entering and leaving the ES by means of thermocouples placed directly into the flow. The inlet pipeline accommodated a heater for preheating the mixture entering the ES. The thermostat temperature was 290 K and was maintained constant throughout the experiment. The condensate plug forms at the 240th second; in so doing, the mass concentration of butane decreased from the initial value of 57% to 32%. Note the decrease in the temperature of mixture in the process of filtration in the ES from 290 K to 265 K.

A similar decrease in temperature is typical of gas condensate in the case of filtration from deep in the stratum into the bottom-hole formation zone in the vicinity of the well because of the effect of throttling of condensate in the pore space [3]. The recovery of initial flow rate and composition of the mixture was registered after the temperature of the incoming mixture was increased to 350 K. The results of the series of experiments both with increasing thermostat temperature and with increasing temperature of the mixture entering the thermostat are qualitatively similar.

CONCLUSIONS

The investigations revealed the possibility of using a physical model of gas condensate (methane–n-butane binary mixture) for attaining the effect of formation of gas-condensate plugs under conditions corresponding to the retrograde region of phase diagram methane concentration of 43–50%, temperature of the mixture up to 310 K). An abrupt decrease in the mixture flow rate is observed as a result of plug formation.

An experimental investigation was performed of the thermal effect on the condensate plug formed. It has been demonstrated that the temperature increase to 340 K results in the recovery of the flow rate of mixture and of the concentration of components.

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