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Application of the Gas Ejector for Water-Alternated-Gas Injection for Heterogeneous Oil Carbonate Formations

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Abstract. The article considers questions of ejecting devices for produced water saturation with compressed nitrogen application considering the water-alternated-gas injection technological process implementation. The WAG process effectiveness, based on the laboratory researches results and hydrodynamic simulation, was represented. In particular, displacement efficiency increase was represented. Ejector application for gazing of the water in the reservoir pressure maintenance (RPM) system is under consideration. There was simulated the ejection process in a supersonic ejector in order to define the effect of nozzle critical diameter and draft surface area on the performance parameters of the device. Control efficiency of the device ejection coefficient due to the draft surface area changing was shown. Draft surface area influence on the gas pressure value in the ejector exit is determined. Opportunity of gas ejector application for associated gas water-alternated-gas injection was represented.

INTRODUCTION

One of the most severe problem of oil extracting industry in Russia is large amount of mature production fields having low extraction ratio, production rate decrease and high water cut on the one hand along with large amount of geologically complex production fields having high core sample shaliness and high oil viscosity on the other. In this circumstances development of efficient stimulation techniques for the heterogeneous oil formations becomes a relevant and important task. This research describes the gas ejector application in order to ensure required casing head gas pressure for water-alternated-gas injection method implementation.

The experience of such oil-pool development efficiency improvement both, in Russia and abroad, indicates that there are technologies capable to change the hydrodynamic performance of separate interlayers, to achieve water injection front leveling and to reduce ineffective injection volume even for such rough geological conditions. In particular, methods associated with water-alternated-gas (WAG) injection [1] are related to such technologies.

The application of WAG injection technology on specific sites requires application of ejecting or power assisted devices for bottom water saturation with compressed nitrogen. Gas ejector application requires researches on ways of ejection coefficient [2,3] change automation without any additional structural change of the device as well as study of outlet pressure level relation to the design parameters of the device.

It should be noted that the task to develop a new technology-enhanced gas ejector design providing hardware control (ejection rate variation) without any supplementary maintenance remains relevant [2,4,5]. The efficiency of newly designed ejectors also requires improvement, involving increase of low pressure gas volume, supplied into the ejector, relating to the high pressure gas volume coming through the ejector nozzle (ejection coefficient) [7,8] along with gain in performance and environmental improvement of new devices. In spite of the significant interest of the researchers to the problem of ejecting devices effectiveness improvement [2,4-6] the gas-dynamic processes inside the ejector operating path remain understudied.

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This article studies the tasks of gas ejector application in order to provide the associated gas pressure required for water-alternated-gas injection method implementation.

RESEARCH OF WAG INJECTION TECHNOLOGY EFFECTIVENESS

The given operating procedure involves gazing of the stratal and bottom water flowing into the reservoir pressure maintenance (RPM) system with an accompanying gas (N) precompressed inside the injecting device or booster unit up to 15 MPa. Gas cut bottom water under the pressure of 15-20 MPa is supplied to the RPM system.

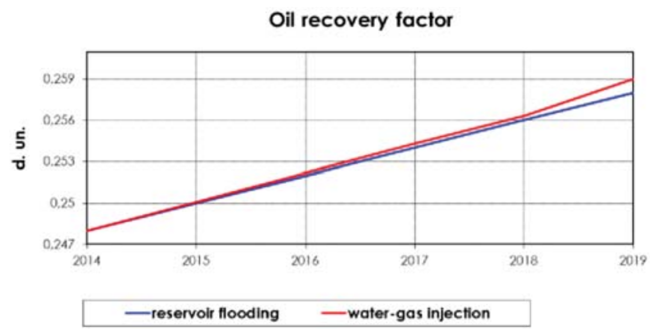


FIGURE 1. ORI increase due to application of all operating injection well stock for water-gas mixture injection

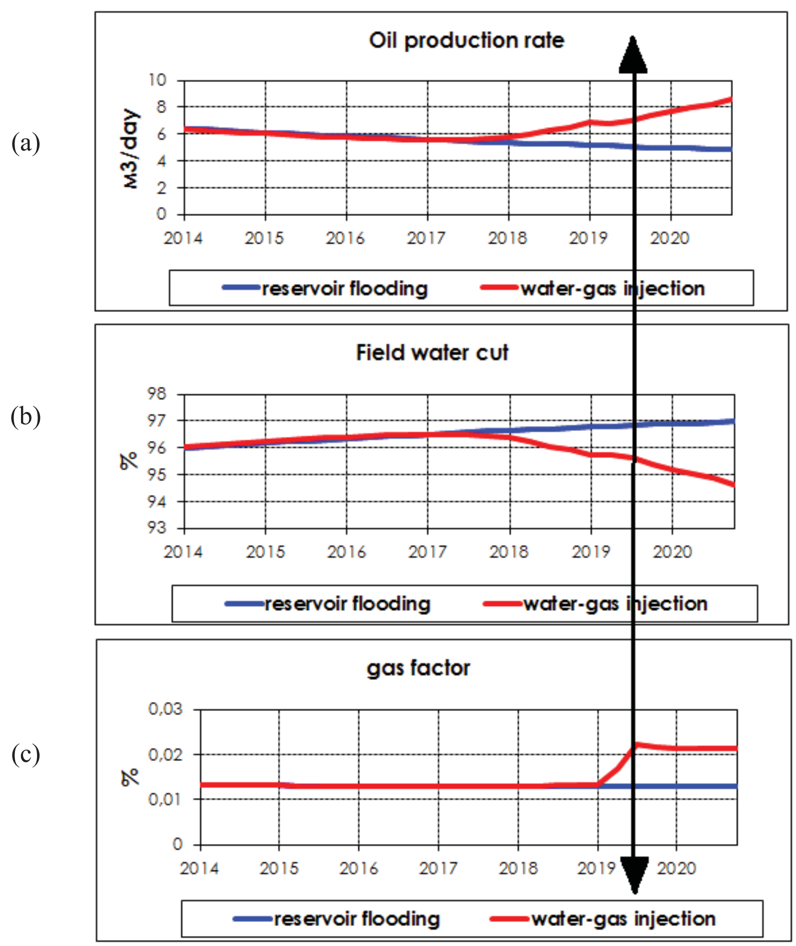


FIGURE 2. Results of the hydrodynamic simulation: (a) Oil production rate, (b) Field water cut, (c) Gas factor

This technology was tested by laboratory filtering experiments [1] performed at natural saturated core on one of the oil fields of Udmurt Republic containing carbonate deposits. The experiment displayed the technology of stable state water-gas mixture injection with various gas concentration. Nitrogen was used as gas. Experiments proved (Fig. 1) that water-alternated-gas injection method provides oil recovery factor (ORF) increase along with the efficient use of casing head gas volume increase.

Laboratory tests results were approved during the hydrodynamic simulation. Two versions were calculated on a testing site for simulation object, they are: conventional water flooding and water- gas mixture injection. The simulation with injection was applied for one of the injection wells that demonstrated its effectiveness (Fig. 2).

NUMERICAL SIMULATION OF GAS EJECTOR GASDYNAMICS

Quasi-steady flow of turbulent viscous compressible gas [8] in a gas supersonic ejector exhaust duct (Fig. 3) is under consideration. The study considered structural control parameters such as: nozzle throat diameter (critical) 1-d and suction chamber 2-S draft surface area.

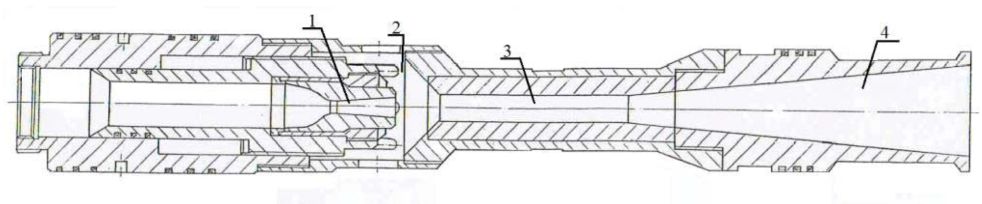


FIGURE 3. Ejector exhaust duct scheme:
1 – nozzle, 2 – suction chamber, 3 – mixing chamber, 4 - diffusor

(a)

(b)

(c)

FIGURE 4. Streamlines in a ejector flow ducts (a), contribution of the main inflow (b), contribution of the gas draft (c)

Nonstationary flow of viscous compressed gas is described by closed system of Navier-Stokes equation and is added by perfect gas state equation. The initial equation system is Reynolds-averaged in order to describe the turbulent flows. The resulting equation system is closured using two-equation turbulence model SST k-ω. The ejector working medium is nitrogen that is considered as perfect gas having adiabatic exponent g = 1.404 and gas constant R = 296.8 J/(kg · C).

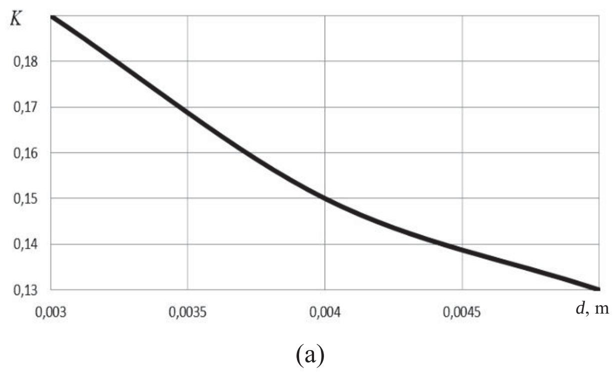
The boundary conditions formulated in the following way: incoming channel mass flow is set as Q and temperature – as T_1, the draft areas had absolute conditions i.e. pressure –p and temperature – T_2, the outlet conditions were set as non-reflective boundary ones.

The result of calculations is determined flow structure, space and limiting streamlines, longitudinal and cross section velocity vector fields and gas-dynamic parameters distribution in a channel. Let's consider the flow structure in the working volume of the ejector. Figure 4 shows the flow streamlines in a flow ducts. Dark areas correspond to low flow speed and light ones – to high speed flow areas.

Figure 4, a shows that the flow in the ejector bulk is generated by two flows action i.e. main flow (high pressure) and draft flow (low pressure), but Fig. 4, b and 4, c demonstrate that main flow is generated by the stream core in an exit core and the near wall flows are generated due to the influent low pressure gas. Analyzed results demonstrated the relation of hydraulic pressure losses coefficients and ejection of the device (Fig. 5) to the ejector structural parameters.

Figure 5 shows that critical diameter d increase leads to the ejector efficiency decrease and the ejection coefficients are most effectively controlled by the draft area variation. More over, the ejection coefficient curve saturation is detected when threshold limit value of draft area is reached. So, the optimum range of the draft area variation is 1.5S.

It was also detected that ejection draft area variation doesn't influence the gas-dynamic losses in ejector cross section. Thus the ejecting device control, required for the represented water-alternated-gas technology, can be performed due to the draft area surface change.



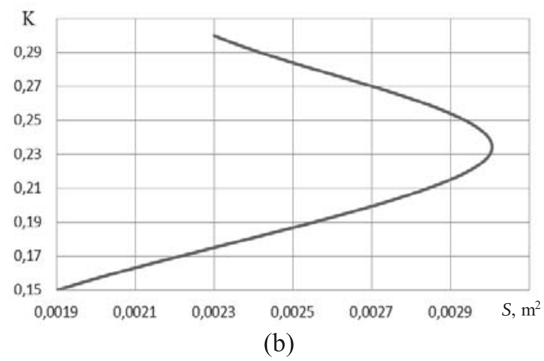


FIGURE 5. The dependence of the ejecting coefficient from throat diameter d (a) and from the draft area surface value S (b)

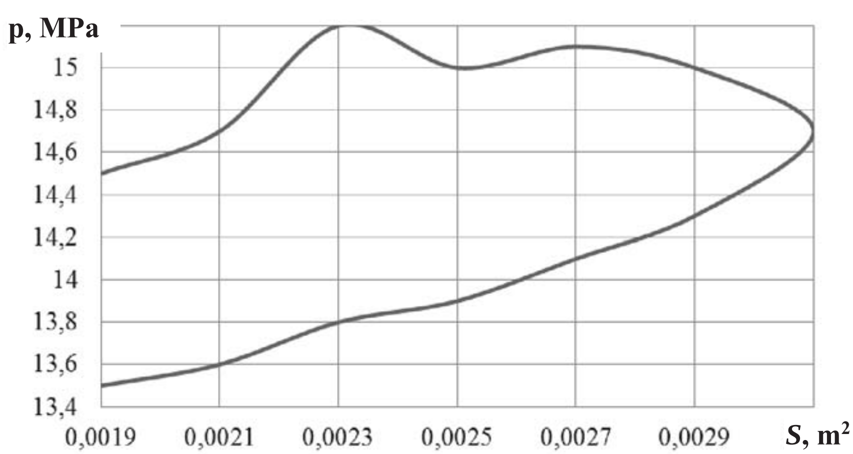


FIGURE 6. Correlation of the draft surface area value S

Due to the analyzed results the relation of ejector outlet pressure change (Fig. 6) to the draft surface area was detected. Figure 6 shows that outlet maximal pressure for the observed initial conditions is achieved during the draft surface area change ranging from 1.21 to 1.52 S that correlates to obtained ejection coefficient relations. It should also be stated, that the maximal pressure exceeds 15 MPa that correspond to the required level of bottom water gas saturation.

In view of this, as the required ejector outlet pressure level was achieved, the presented ejector design, considering the variated draft surface area, can be applied to provide the associated gas supply to the bottom water mixing system for future injection into the layer as WAG injection.

CONCLUSION

The study considers gas flows in the exhaust duct of the ejecting device. It is discovered that operation nozzle throat diameter variation leads not only to the gas ejection coefficient change but to corresponding change of the hydraulic losses. It is found, that draft surface area doesn't influence the gas-dynamic parameters distribution (including the hydraulic losses through the ejector cross section) so the ejection coefficient control using ejecting gas draft surface area variation is more effective and reasonable.

The potential application of gas ejector design provides hardware control that doesn't require device shut down and additional maintenance in order to change the ejection rate that provides associated gas pressure water-alternated-gas injection method application.

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