Quick detection of gusts and its location in the reservoir pressure maintenance system

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Abstract. The article devoted to theoretical and methodical materials based on the researches conducted within trial tests reverse ultra-sonic flow meters on different areas of exploited oil fields.

Introduction to the system of maintenance of reservoir pressure

Most of the largest produce fields in Russia are exploited at a late stage of production. Residual reserves of such deposits are classified as hard-to-recover. According to various estimates, proportion of hard-to-recover reserves today exceeds half with water cut over 80%, and the average of oil recoverability factor (ORF) is between 20% and 43% in Russia. The most effective way to maintain of oil production from produce fields that are at a late stage of production is the method of waterflooding the oil deposit, which is carried out by the reservoir pressure maintenance system (RPM). The main task of RPM system is the maintenance of reservoir energy, through which fluid is withdrawn from the collector of reservoir rock through exploitation well.

The RPM system is a complex engineering infrastructure that includes facilities for preparing process fluid, pump stations, pipelines and a fund of injection wells. Such an infrastructure, together with oil reservoir into which water is pump, is an even more complex system that, when problems solving of effective injection, must be considered as a single integrated system.

Problems that arise in the MRP systems

In any complex system in which process is performed on the transformation and transfer of energy, inevitably there are losses. In the RPM system magnitude of such losses can reach significant values that affect the economy of oil and gas production enterprises, which amount to tens and hundreds of millions rubles. This article considers the issue of incident detection that are associated with gusts of pipelines, a deformation of the design of injection wells and other accident in which there are losses of water, electricity reservoir pressure of the exploited reservoir.

The solution of such a complex main task is impossible without modern measuring gauges, remote monitoring systems for the parameters of the system operation, mathematical and software.

Searching for solutions to the existing problems

Nowadays, a large number of affordable devices have appeared that allow measuring and processing the measure values of the monitored parameters (test items) with the necessary and sufficient discreteness to solve complex problems in determining process losses. This allows to
differently analyze the already known physical processes in the RPM system, eliminate information gaps in determining the dynamics of physical processes and accurately determine the behavior of the parameters of the engineering infrastructure and the exploited reservoir.

Case study of the hydraulic characteristics of the bottomhole formation zone allowed to determine the complete similarity with the electrotechnical dependences of direct-current circuits [1]. It turned out that dependences of the main parameters of the “formation-well” system are identical to the electrical circuit (drawing) realized as part of integrating resistor-capacitor (RC) direct-current circuits. The given conclusion is made on the basis of application of the known laws deduced for the direct-current circuits to hydraulic processes of system “formation-well” which are below-specified [2].

The characteristic of the bottomhole pressure change during impulse function coincides with the characteristic of the electrical voltage on the capacitor plate of the integrating RC circuit. Detailed study of impulse function process on the “formation-well” system received this supposition [3]. It turned out that the behavior of the bottomhole formation zone with impulse function on the pressure of the fluid intake point at the bottom of the well is similar to the behavior of the electrolytic capacitor in the RC circuit [4].

Such an RC circuit is called an integrating network section, since this section is able to accumulate and donate a charge of electricity. The capacitor, like the bottomhole formation zone, has one interesting property – when it is discharged, it behaves almost like short-circuited, the current through it flows without limitations, approaching to infinity, and the voltage drop on it approaches to zero. When the capacitor is charged, the current becomes zero, and the voltage on it becomes equal to the voltage of the power source. The same happens with the bottomhole zone in the injection wells. When the pressure in the face takes the minimum value, the water flow in the injection well is rapidly increasing. As the formation pressure rises, the water flow decreases. It turns out interesting dependencies: for the capacitor there is a current, there is no voltage, there is a voltage there is no current, for the bottomhole formation zone the formation pressure increases, the water flow decreases, the pressure in the bottom drops, the flow increases, the parameters are different, and the regularities are the same.

An example of such a process was recorded at the remote distribution point RDP-5 at the water injection station (WIS) of the WIS-58 “Jalilneft”, which is equipped with reverse flow meters capable of registering hourly integral flow readings in the memory of device. Figure 1 shows the readings of water flow devices taken at a daily time interval, within which the pumping unit on the WIS was turned off and restarted after a certain period of time.

A balance group has been established at this facility, where water pumped into the reservoir through the water lines 12 and 13 is supplied to RDP-5 from the WIS 58, and water is supplied to the injection wells via the water pipes 6, 7, 8 and 10. From figure 1, we see that after the unit shutdown at the WIS 58, the water flow in the injection system does not stop. After stopping the unit on the water channel 8, the direction of the fluid flow changed to the opposite direction.

The accuracy of the measured values of water flow is confirmed by the material balance equation, quantity of flooding water is equal to the quantity expended water. The average relative divergence of the balance for the day was less than one percent, which confirms the high accuracy of measuring the integral costs at hourly intervals.
According to the theory of electrical engineering, the reaction of a circuit of an integrating type to a single stepped action of a voltage with an amplitude $U$ is given by the following formula:

$$U_c = U_0 + U (1 - e^{-t/\tau})$$,  \hspace{1cm} (1)$$

where $U_0$ is the initial value of voltage on the capacitor plates; $U$ is the voltage pulse applied to the RC circuit; $\tau$ is a time constant equal to the product of the resistance to the capacitance of the capacitor,$$
\tau = RC. \hspace{1cm} (2)$$
Figure 2 shows a graph of the voltage variation across the capacitor plates when the time changes, which is a multiple of the time constant $\tau$. For the bottomhole formation zone by analogy with the RC circuit, a stepwise effect on the bottomhole pressure $P_{bp}$ will be written similar to the mathematical dependence:

$$P_{bp} = P_{iv} + P(1 - e^{-\frac{t}{\tau}})$$  \hspace{1cm} (3)

where $P_{iv}$ is the initial value of bottomhole pressure; $P$ is the pressure pulse; $t$ is the time; $\tau$ is the time constant, which is equal to the product of the hydraulic resistance of the bottomhole formation zone by the bottomhole zone capacity factor:

$$\tau = R_{bf}C_{bf}.$$  \hspace{1cm} (4)

According to the energy conservation law, the total mechanical energy that performs the work of moving a certain volume of fluid from one point of the pipeline network to another consists of the sum of the potential and kinetic energies, and this sum is constant:

$$E_{total} = E_{pot} + E_{kin} = const,$$  \hspace{1cm} (5)

where $E_{total}$ is the total mechanical energy, $E_{pot}$ is the potential energy, $E_{kin}$ is the kinetic energy.

For the energy of pressure, the energy conservation law is written in the form of the Bernoulli equation:

$$P + \rho gh + \frac{\rho V^2}{2} = const,$$  \hspace{1cm} (6)

where $P + \rho gh$ is the hydrostatic pressure or potential energy of pressure; $\frac{\rho V^2}{2}$ is the hydrodynamic head or kinetic energy of pressure; $\rho$ is the water density.

Considering the conditionally constant value of the water density and that the water is an incompressible liquid, for the pipeline of the RPM system having two water accounting points in which there are flow meters and pressure sensors, the Bernoulli equation will have the following form:

$$P_1 + \rho gh_1 + \frac{\rho V_1^2}{2} = P_2 + \rho gh_2 + \frac{\rho V_2^2}{2} + P_{pot} = const,$$  \hspace{1cm} (7)

where $P_1, P_2$ are measured pressures at points of shipment and reception of water; $V_1, V_2$ are the measured values of the water velocity through the cross section of the water flow meters; $h_1, h_2$ are geometric marks of flow meters and pressure sensors installation at the points of shipment and reception of water; $P_{pot}$ is a loss of pressure in the pipeline network between water metering points 1 and 2.

The pressure losses in the steady-state injection regime are conventionally constant, and these losses can be determined experimentally by equation (7).

The engineering infrastructure of the RPM system consists of three levels, which are conventionally depicted in Figure 3.
The first level of the engineering network contains a balance group of water conduits with water meters that combine water treatment facilities and water injection stations.

The second level includes the balance group of water conduits with water flow meters between water injection station and manifold units at the water injection station and remote distribution points.

The third level consists of water conduits that combine manifold units and remote distribution points with injection wells. In the third group, as a rule, there are no balance groups; flow meters are installed only at the points of water shipment, there are no flow meters at the wellheads of the injection wells.

For the first level of the RPM system, having equipped water metering units with reverse flow meters and pressure sensors at the points of shipment and reception, equation (7) can determine the possible gusts of the pipeline network and also solve inverse problems to detect malfunctions of flow meters and pressure sensors.

The second level is provided by controlling the balance of the volume of the pumped liquid according to the integrated readings of the flow meters.

The third level of control is the most difficult, because there are flow meters at the points of water shipment to manifold units and remote distribution points, and there are no flow meters at the injection points at the wellheads of the injection wells. But, knowing the modes of pumping units operation at the WIS, and also controlling the injection of water in a stationary mode, using special algorithms for processing the measured values of pressures at points of the pipeline network that are common to several pipelines, it is possible, with the help of the same energy conservation law (7), with a high accuracy determine the time of occurrence of incidents, the magnitude and nature of the current changes.

Incidents are events that lead to a change in the operation of water injection in the RPM system. Incidents include: start-ups or shutdowns of pumping units; planned or unplanned changes in injection modes, including the opening or closing of individual conduits with pumping units operating at the WIS, which leads to a redistribution of costs in the water conduits and changes in pressures in common reservoirs: gusts of pipelines or disturbance of the well design.

To determine the nature of the incident, whether the incident is an accident or simply a planned measure for changing the operating mode, special algorithms are applied which, by the equation of the transient process (3), determine the magnitude of the pressure pulse and the time constant of the transient process by solving the inverse problem. For certain parameters of the amplitude of the pressure change and the time constant of the transient process, a special algorithm of the program of the remote control and monitoring system allows identifying the emergency events and changing the injection modes that do not affect the failure of the infrastructure of the RPM system, for example, the planned opening or closing of the water conduit with the WIS running.
The most difficult for automatic detection is to determine the possible disruption of the injection well design.

Figure 4. Design of the injection well.

Figure 4 shows the design of the injection well. The change in injection modes can be affected by the violation of the production tubing tightness, the production strings, and the packer. With such disturbances, latent pressure losses occur in the contour of the bottomhole zone of the injection well. Wells in which such disturbances occur after stopping the pumping units on the WIS begin to take water that is poured from other injection wells with greater hydrostatic pressure.

With the help of reversible counters, the direction of the water lines is directed to which water flows are directed after the pump units are stopped, and if more than one well is connected to the direction, the well that receives water after stopping the aggregates at the pump station is determined by successive shutdown of the wells. The magnitude of the pressure pulse amplitude (7) determines the nature of the problem in the injection well. To accurately determine the problem, hydrodynamic studies of the design of the injection well are carried out.

The theoretical and methodological materials outlined in this article are based on the studies carried out in the framework of pilot-scale tests of reverse ultra-sonic flow meters in different sections of the produce fields. The use of reverse flow meters in the automated system of remote control and management allowed us to identify a large number of sections of the pressure maintenance system in various OGPDs in which uncontrolled outflow of water occurs after the pumping units are stopped. In some areas, the volumes of spills reach 20% of the volume of water pumped into the reservoir. This indicates a greater efficiency compared to the methods already known [5,6,7].

The mass proportion of this problem for many OGPDs operating the field at a late stage of extracting requires a systems approach in solving the problem of determining the losses and increasing the efficiency of the MRP system's operation.

References
[1] Neprimerov N N 1962 Dissertation for the degree Doctor of Sciences Experimental studies of some issues of underground hydromechanics and physics of the “formation-well” system (Kazan)
[2] Neprimerov N N 1986 Technology for optimum production of the reservoir (Kazan)
[3] Ibragimov N G, Panarin A T, Desyatkov V K, Evtushenko S P 1996 The materials of seminar-discussion "the Concept of development of methods of increasing oil recovery" To the question of determining the optimal period of water injection in carbonate reservoir (Bugulma)
[4] Petrenko Y V 2016 *Theoretical foundations of electrical engineering. Transient processes in linear electric circuits: a tutorial* (Novosibirsk: publisher Novosibirsk State Technical University)

[5] Ahmed M Sattar and M Hanif Chaudhry 2008 *Journal of Hydraulic Research* vol 46 *Leak detection in pipelines by frequency response method*

[6] Witness Mpesha, M Hanif Chaudhry and Sarah L Gassman 2002 *Journal of Hydraulic Research* vol 40 *Leak detection in pipes by frequency response method using a step excitation*

[7] Jin Yang, Yumei Wen, Ping Li and Xingke Wang 2013 *Urban Water Journal* vol 10 *Study on an improved acoustic leak detection method for water distribution systems*