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Research paper



Increase in Fluid Extraction in the Field at the Final Stage of Development

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Abstract

It has been established that the fluid reserves, which are at the final stage of development, are difficult to extracta and water. The methods of intensification are analyzed and it is established that it will be rational in this case to pump carbon dioxide into the reservoir. Its influence on a bundle of oil and water is determined. The results of the statistical processing of the change of the debit before and after injection of carbon dioxide, the influence of the volume of gas injected into the well from the seperate permeability of the reservoir, as well as the expected rate of wellbore after injection, are presented.

Keywords: *productive layer, carbon dioxide, fluid, water content, viscous oil*.

1. Introduction

The industrial problem of the oil industry is due to the fact that, as a result of the more intensive development of easily recovered oil fields, the share of hard-to-recovered reserves is constantly increasing, requiring the application of new methods of increasing oil production.

Using standard technologies, we can not withstand the necessary efficiency to extract tall and residual oil, oil from deposits with unprotected reservoir energy and to avoid high flooding, therefore, to find new ones or to improve already existing methods of intensification. Nowadays, dozens of different methods of influencing oil deposits and increasing oil extraction (primary, secondary, tertiary) are known and implemented in industrial practice. Among them there are four main groups [1]:

1) hydrodynamic methods − cyclic flooding, change of direction of filtering flows, creation of high injection pressures, forced liquid removal, as well as methods of influence on the grapple zone;
2) physical and chemical methods − flooding with the use of active impurities (surface-active substances − surfactants, polymers, alkalis, sulfuric acid, micellar solutions);
3) gas methods − - water gas cyclic impact, displacement of oil by gas of high pressure, injection of hydrocarbon dioxide, nitrogen, flue gases;
4) thermal methods − the displacement of oil by heat-carrier (hot water, steam), steam cycling of the reservoir, in-shell combustion, use of water as a thermo solvent of oil.

The use of methods for raising oil extraction from deposits is determined by geological and physical conditions. The known methods are characterized by a different potential increase in oil extraction from deposits (from 2 to 35% of balance stocks) and various factors of their application.

One of such complex methods is the injection of carbon dioxide (CO_2) into the formation. The physical essence of the method is the good solubility of carbon dioxide in formation fluids, which provides a volume expansion of oil in 1.5− 1.7 times, the ability to mix it with oil (removal of capillary forces), reducing the viscosity of oil (from tens percent to several times) and, as a consequence, an increase in the crowding rate (up to 0.95).

However, the application of this gas, as well as any other low-viscosity agent, is accompanied by a decrease in the coverage factor (by 5− 15%), which can lead to an increase in the oil extraction rate of only 7− 12%.

2. Main body

The injection of CO_2 into the reservoir is one of the most effective ways to increase oil recovery. Dioxide of carbon, as well as hydrocarbon solvents, provides a very high percentage of extraction and is deprived of their basic disadvantages − the price of the juice.

Carbon dioxide forms a liquid phase at temperatures below 310 ° C. At the temperature above 31 ºC, carbon dioxide is in a gaseous state, with a pressure of less than 7.2 MPa − from the liquid passes into a vaporous.

The principle of applying [4] CO_2 is based on the dependence of the viscosity of fluids in reservoir conditions on the amount of CO_2 dissolved in them. For example, the dissolution of CO_2 in oil reduces its viscosity within 10-50%. At the same time, the volume ratio of oil with dissolved gas increases to 50%.An increase in the volume of oil contributes to the growth of the volume of pores occupied by oil, creates favorable conditions for its movement. Reducing the viscosity of the oil leads to an increase in its mobility. In this regard, in order to achieve a given coefficient of oil consumption, a smaller amount of displacing agent is spent.

Due to the solubility of CO_2 in reservoir water, the initial viscosity of water is noticeably increased, as a result of the ratio of the movement of oil and water increases. Dioxide of carbon in the

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system also leads to a decrease in the surface tension at the boundary of oil − water.

Efficiency of displacement of oil by carbon dioxide is determined both by increasing the coefficient of coverage by the effect and displacement. The increase in the coverage factor by area and volume is due to improved capillary absorption and equalization of the mobility of water and oil.

The ability of carbon dioxide to be readily dissolved in oil and water is a key property that determines the high efficiency of oil displacement with the use of carbon dioxide.

This property also contributes to the separation and washing of the oil film from the top of the rock, increases the wettability of the porous medium with water and thus contributes to capillary water collection in a porous medium saturated with oil, resulting in an increase of the amount of oil displaced. Depending on the composition of oil, pressure, temperature, the solubility of CO_2 in it may be either limited, or close to unlimited. The solubility of carbon dioxide in real oil can reach hundreds of volumes of CO_2 per one volume of oil. So, in other equal conditions, carbon dioxide is better soluble in petroleum with a high content of hydrocarbons in the C_3−C_7 series. The high content of resins and asphaltenes in oil, on the contrary, greatly complicates its dissolution. For this reason, unlimited solubility of carbon dioxide in oil is practically impossible.

Dioxide of carbon, depending on the thermodynamic conditions (pressure, temperature) can be in solid, liquid and gaseous state (Fig. 1).

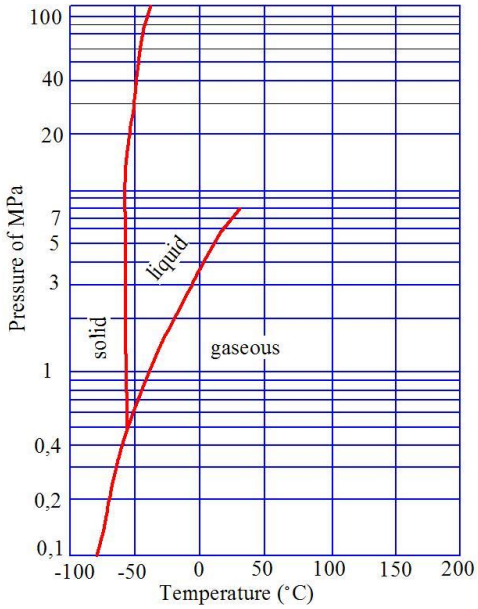


Fig. 1: Carbon dioxide phase diagram

In the chart below, one can judge what kind of oil displacement using carbon dioxide will occur at specific reservoir temperatures and pressures. So, if [5] the formation temperature is <319ºC. and pressure > 7.5 MPa, then the oil will be replaced by liquid carbon dioxide. If the formation temperature is> 31 ºC, the most likely is the displacement of oil by carbon dioxide.

The gaseous carbon dioxide is colorless, has a slightly sour smell and taste. The molecular weight of the compound is 44,010. The density of CO_2 at normal pressure and temperature 0^0C is 1.98kg/m^3.

With increasing temperature under constant pressure and oil composition, the efficiency of CO2 in it decreases. With constant oil composition and temperature increase of pressure causes increase of solubility of carbon dioxide.

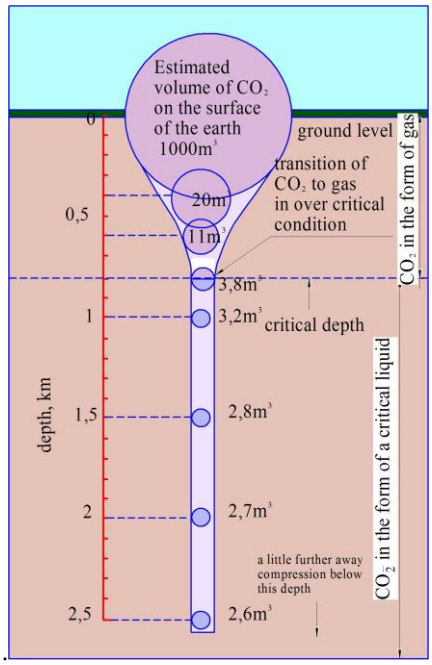


Fig. 2: The scheme of transition of carbon dioxide into a liquid state

Dioxide of carbon dissolves sufficiently well in water. However, this process is limited in nature. It is influenced by pressure, temperature and degree of mineralization. So, with increasing pressure at constant mineralization and temperature, the solubility of carbon dioxide in water rises. With constant mineralization of water and pressure with increasing temperature the process is ambiguous. When [4] constant pressure and temperature with an increase in mineralization, the solubility of CO2 in water decreases. Depending on the specific conditions, the solubility of carbon dioxide in water can reach 20%.

The aqueous solution of carbon dioxide reacts with carbonates in kind, dissolves them, while increasing the permeability of the collector and absorbing the ability of the injection wells. When pressure are constant and the temperature increases, the sobulity of CO_2 in water decreases.

So, with the increase in the content of dissolved CO_2 depending on the composition of oil, pressure, the degree of pressure and temperature, there is a decrease in the viscosity in 2-15 times compared with the initial at zero content of carbon dioxide, while for more viscous oil in much higher degree than for less viscous.

With increasing pressure at constant values of the initial composition of oil and temperature, its viscosity with CO_2 dissolved in it takes ever lesser significance. This is due to the increase in the content of dissolved carbon dioxide in oil.

With the constant composition of oil and pressure with increasing temperature, the viscose oil when dissolved in it, CO2 is reduced to a lesser extent, as the solubility of carbon dioxide also decreases. Knowledge of the mechanism of reducing the viscosity of oil when dissolved in it, CO_2 is necessary in the prediction of technological indicators of processes of displacement of oil using carbon dioxide.

At constant saturation pressure with increasing concentration of carbon dioxide the density of oil increases. Increasing the pressure above saturation pressure also contributes to increasing its density. As the temperature rises, it decreases. The pressure, the composition of oil, the ratio of volumes of gas and oil and temperature affect the change in the density of oil with dissolved CO_2 to the same extent as these factors affect the very solubility of carbon dioxide in oil. When carbon dioxide is dissolved, carbon dioxide is formed in water, which, interacting with carbonate rocks - dolomite, sandstone with carbon-tinny cement, leads to an increase in porosity, permeability, degree of heterogeneity of these rocks.

The mechanisms discussed above for reducing the viscosity and increasing the volume of oil when dissolved in it, carbon dioxide

leads to an increase in the mobile-state of the oil phase, which facilitates the displacement of oil. In addition, there is an increase in phase permeabilities for oil and water when they are in contact with CO_2.

Thus, carbon dioxide [9] when interacting with oil, water and the rhizome phase causes a change in the physical and chemical properties of the latter.

Carbon dioxide or carbon dioxide forms a liquid phase at temperatures below 31ºC. At a temperature above 31 ºC, carbon dioxide is in a gaseous state, with a pressure of less than 7.2 MPa − from the liquid passes into a vaporous.

The technological scheme of injection of CO2 is based on the existing general scheme of industrial arrangement of the deposit and, in particular, on the use of objects of the existing flood system. At the same time it is possible to supply CO_2 to well, using the injection pipelines of the existing production system, to build new pipelines or to deliver tanks.

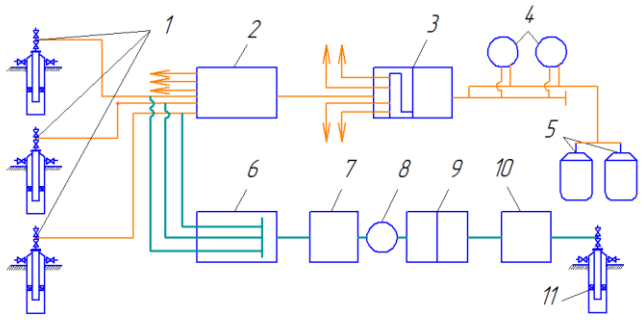


Fig. 3: Technological scheme of injection of CO_2: 1 - injection wells; 2 - point of distribution CO2; 3 - pumping station; 4 - buffer tanks for CO_2; 5 - CO2 tanks; 6 - pressure head of the flood system; 7 - block bush pumping station; 8 - buffer tanks; 9 - the main pumping station and water treatment station; 10 - station of the first lifting; 11 - water well.

The CO_2 is pumped into the reservoir on the column of the pump-compressor pipes. For maintenance of the operating column from corrosion and high injection pressures, created when the CO_2 is injected into the formation, into the injection wells, injecting the packer devices. Wells are equipped with a standard fitting with the necessary devices to control the process of pumping CO_2 into the formation.

To pump CO2, special acid-proof pumps with remote control and automatic protection are used. For a continuous supply of CO_2 in the pumping station, reserve pumps are provided. All technological pipelines of a pumping station should be calculated on a pressure with a 1: 4 stock ratio.

The hydrocarbonic acid of H_2CO_3 formed during the dissolution of CO_2 in water dissolves cement in the formation of the formation and thus increases the permeability. Dioxide of carbon in water contributes to the breakdown and "laundering" of film oil that covers the grain of the breed and reduces the possibility of breaking the water film.

At reservoir pressure above [8], the pressure of complete mixing of carbon monoxide from carbon monoxide will suppress oil as an ordinary solvent (mixing displacement).

In a layer three zones are formed:

1) the zone of primitive reservoir oil;
2) transition zone;
3) a zone of clean CO_2.

If CO_2 is injected into a flooded deposit, then a CO2 shaft is formed in front of the CO_2 zone, which displaces the formation water.

Dioxide of carbon has oil-retaining properties, due to its abilities:

1) readily dissolve in oil and in sewage water, and vice versa, dissolve in itself oil and water.
2) reduce the viscosity of oil, and increase the viscosity of water when dissolved in them, reducing the mobility of water relative to oil.
3) to increase the volume of oil when dissolved in it CO2 and to increase the efficiency of displacement of oil. [10]
4) to reduce the interfacial tension on the edge of oil and water, to improve the moisture of the rock with water when dissolved in oil and water and to ensure the transfer of oil from the film state to the drip.
5) Increase the permeability of individual types of collectors as a result of chemical interaction of coal and rock skeletons.

With the displacement of CO_2 oil, depending on the specific conditions, different schemes may apply (Table 1).

Table 1: Mechanism and schemes of influence

Scheme of influence	Thermodynamic constraints		Characteristics of the fluid: components, phases
	By temperature	By pressure	
Exhaust gaseous CO_2	$T < T_{кг}$ $T > T_{кг}$	$P < P_s$	Gas phase: CO2. Liquid phase or gas-liquid mixture: hydrocarbons (petroleum)
Exhaust gaseous CO_2	$T > T_{кг}$	$P < P_s$	Carbon dioxide, oil
Displacement with mixing	$T < T_{кг}$ $T > T_{кг}$	$P > P_{mix}$	1. Liquid hydrocarbon phase. 2. A gas-liquid zone: a mixture of explosives and carbon dioxide. 3. Zone of complete mutual solubility: gaseous mixture of hydrocarbons and CO_2 (without boundaries of phases). 4. Propagation zone: gaseous (predominantly) or liquid (sometimes) CO_2. 5. The zone of complete mutual solubility is absent.
Displacement with carbonated water	$T < T_{кг}$ $T > T_{кpr}$	$P_{pl} < P_{mix}$ $P > P_{solution}$	Oil phase: hydrocarbons and CO_2 (insignificant quantity). Water phase: water and CO_2 (high content). Gas phase: hydrocarbons and CO_2.

Displacement with mixing. The displacement scheme is carried out by feeding both gaseous and liquid carbon dioxide into the formation. Prerequisite is Ppl> Rm (mixing), the pressure at which the total mutual dissolution of the displacing agent and the extruded medium occurs. The mixing pressure depends on the temperature and composition of the formation oil, which is generally characterized by the molecular weight.The displacing agent zone in which carbon dioxide is located, as a rule, in a gaseous (Tpl> Tcr), or in a liquid state (Tpl <Tcr, Ppl> Ps.). When Ppl <Rism, the zone of complete mutual solubility is absent and it turns out that displacement occurs without mixing. [7]

Oil displacement with gaseous carbon dioxide. At subcritical temperatures in shallow oil horizons and at limited pumping rates provided - P_{pl} (reservoir pressure) <Ps (condensation pressure CO_2). At supercritical temperature (T_{pl}> Tcr, where T_pl is the formation temperature, T = 31,040 ° C is the critical temperature of CO_2), the displacement process is not thermodynamically limited and proceeds at any pressure values in the formation. Elimination of liquefied CO_2. Realized with Tpl <Tkr, Ppl> Ps. Component and phase characteristics of this scheme: repressing agent - liquid CO_2, displaced environment - liquid hydrocarbons and formation water.

The displacement by carbonated water. Is less [8] depends ent on pressure and temperature. With two-phase (liquid-liquid) filtration is taking place, and CO_2 is present in both phases, more in water and less in displaced oil−in the zone adjoining the boundary of the phase separation . Pressure with more pressure of the power of CO_2 in water - P_{solute}.

An aqueous solution of carbon dioxide reacts with carbonate inkind, dissolves them, while increasing permeability. We calculate how the well flow changes after the injection into the carbon diox-

ide layer and how the permeability changes with the following output data (Table 2).

Table 2: Output data for the design of the process of injection of carbon dioxide into the formation

№	Well diameter, m (D)	Volume of carbon dioxide, m³ (Vco_2)	The thickness of the productive layer, m (h)	sponginess m	coefficient of carbonaceous rock	growth rate of permeability k	Power supply radius, m (R_k)	The well flow, tons / day (q_1)	Wateriness of products (n%)
1	0,245	12	11	0,12	5,11	5E-14	850	4,56	55
2	0,089	14	15	0,16	5,96	5E-14	800	3,74	63
3	0,095	17	17	0,16	7,24	5E-14	750	2,23	78
4	0,219	11	10	0,12	4,68	5E-14	700	3,74	63
5	0,273	12	13	0,12	5,11	5E-14	650	3,32	65
6	0,219	15	14	0,16	6,39	5E-14	600	2,88	75
7	0,245	18	18	0,22	7,66	5E-14	550	2,23	78
8	0,273	18	20	0,22	7,66	5E-14	500	1,38	87
9	0,299	12	12	0,14	5,11	5E-14	450	4,56	55
10	0,325	15	16	0,16	6,39	5E-14	400	1,38	63
11	0,351	15	15	0,16	6,39	5E-14	350	1,38	87
12	0,377	11	10	0,12	4,68	5E-14	300		78
13	0,426	17	17	0,22	7,24	5E-14	250	2,88	75
14	0,457	15	15	0,16	6,39	5E-14	200	1,98	80
15	0,508	11	11	0,12	4,68	5E-14	250	2,51	76

The radius of the carbon dioxide penetration zone:

$$r_w = \frac{D}{2} = 0,073м \quad (1)$$

$$R_{CO_2} = \sqrt{\left(\frac{V_{CO_2}}{\pi \cdot h \cdot m}\right) + r_w^2} \quad (2)$$

The permeability of the bottomhole zone of the reservoir after injection of CO2 is equal (according to industrial data):
$c_к$ =0,12 – coefficient of carbonaceous rock

$$k_p = 1.8 \cdot e^{(0.25 \cdot c_k)} \quad (3)$$

k = 2.15 – growth rate of permeability

$$k_{bfz} = k_p \cdot k \quad (4)$$

Average (reduced) reservoir permeability after injection of carbon dioxide:

$$k_m = \frac{k \cdot k_{bfz} \cdot \log(\frac{R_k}{r_w})}{k_{bfz} \cdot \log(\frac{R_{co_2}}{r_w}) + k \cdot \log(\frac{R_k}{r_{co_2}})} \quad (5)$$

Expected effect after injection of carbon dioxide (CO_2):

$$E = \frac{k_m}{k} \quad (6)$$

Determine the expected well flow after loading CO_2:

$$q_2 = q_1 \cdot F \quad (7)$$

where q_1 - the discharge of the well to the injection of carbon dioxide.
Determine the expected oil well after the injection of carbon dioxide, with known water content of the product.

$$q_{2n} = q_2 \cdot (1 - n) \quad (8)$$

This calculation will be carried out 15 times. The obtained results will be analyzed using statistical analysis, and for this we will use the STATISTIKA 10 program.

Table 3: Results of designing the process of carbon dioxide injection

№	Well radius, mr_w	Radiation of carbon dioxide penetrationn, m. Rco_2	Permeability of the bottomhole zone of the formation k_{bfz}	Average reservoir permeability after injection CO_2 $к_m$	Expected effect after injection CO_2 E	Expected discharge of the well after injection $CO_2 q_2$	wells by oil after injection of CO_2, with known water content of products q_{2n}
1	0,12	1,70	3,22E-13	1,22E-13	2,45	11,2	5,04
2	0,04	1,36	3,99E-13	1,16E-13	2,32	8,68	3,21
3	0,04	1,41	5,49E-13	1,21E-13	2,43	5,44	1,19
4	0,10	1,71	2,90E-13	1,15E-13	2,31	8,65	3,20
5	0,13	1,57	3,22E-13	1,25E-13	2,50	8,32	2,91
6	0,10	1,46	4,44E-13	1,31E-13	2,63	7,58	1,89
7	0,12	1,20	6,11E-13	1,50E-13	3,01	6,72	1,47
8	0,13	1,14	6,11E-13	1,56E-13	3,12	4,30	0,56
9	0,14	1,51	3,22E-13	1,25E-13	2,50	11,4	5,13
10	0,16	1,37	4,44E-13	1,40E-13	2,81	3,88	1,43
11	0,17	1,42	4,44E-13	1,40E-13	2,80	3,86	0,50
12	0,18	1,71	2,90E-13	1,18E-13	2,37	5,30	1,16
13	0,21	1,22	5,49E-13	1,58E-13	3,16	9,12	2,28
14	0,22	1,42	4,44E-13	1,41E-13	2,83	5,61	1,12
15	0,25	1,64	2,90E-13	1,25E-13	2,51	6,32	1,51

Having statically processed the results got:
- the dependence of the volume of CO_2 injection from the average reservoir permeability after injection of CO_2, where the correlation coefficient was r=0.995, and Fisher's criterion is equal F=107,02 at a critical point $F_{critical}$ = 161,45

$$Vco_2 = 14,2 + 0,8594 k_m \quad (9)$$

- the dependence of the volume of pumping of CO_2 from the expected debit of the well after the injection of CO_2, where the correlation coefficient r=0.98, and Fisher's criterion F=42,56 at a $F_{critical}$ = 161,45

$$q_2 = -7.8928 + 1.0629\ Vco_2 \quad (10)$$

- dependence of the well flow to the injection of carbon dioxide from the expected value of the well bore at the known watering of the products where the correlation coefficient r=0.998, and Fisher's criterion F=37,824 at a $F_{critical}$ = 161,45

$$q_2 = 4,4664 + 0,9578\ q_1 \quad (11)$$

- dependence of the well flow rate on the injection of dioxide from the expected well flow at the known watering of the products carbon where the correlation coefficient r=0.999, and Fisher's criterion F=33,110 at a $F_{critical}$ = 161,45

$$q_1 = 0,5751 + 0,9934\ q_{2n} \quad (12)$$

Since Fp ≥ Fcritical, the obtained regression equation is assumed to be statistically significant. (The hypothesis of model adequacy was confirmed in all cases)

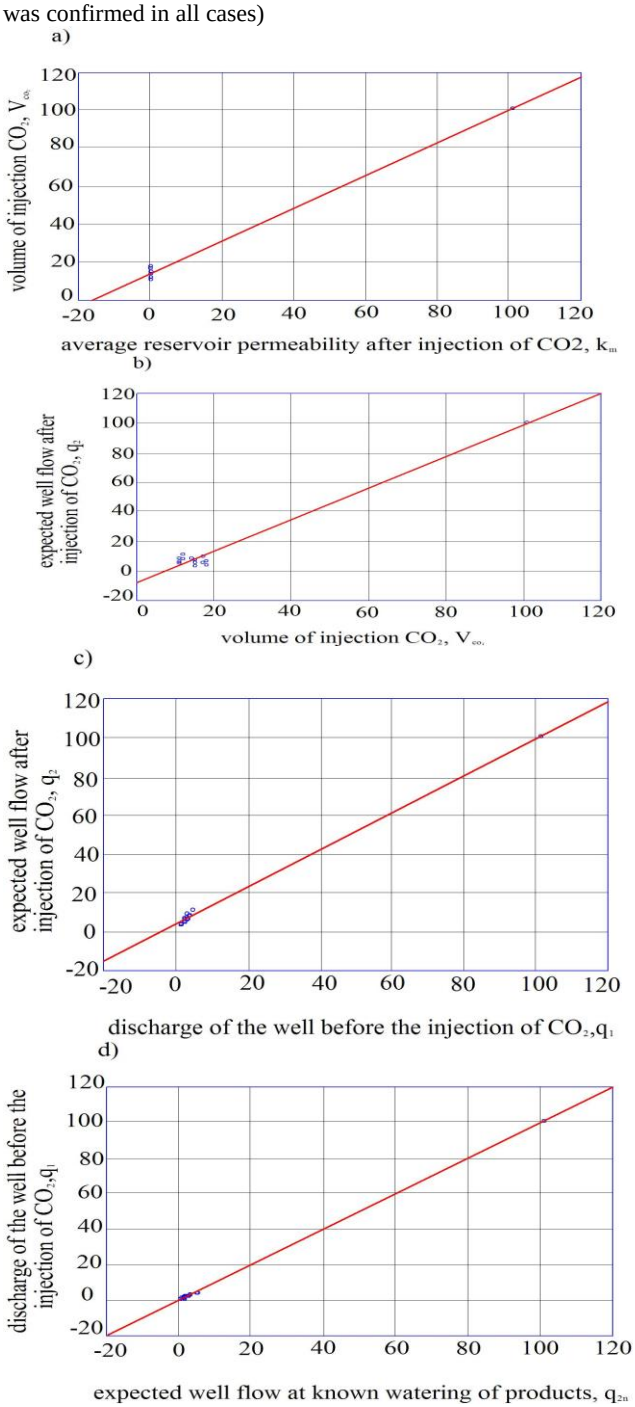


Fig. 4: Graphic dependences of the statistical processing results: a - dependence of the volume of injection CO_2 from the average permeability of the formation after injection of CO_2; b - dependence of the volume of pumping of CO_2 from the expected capacity of the well after the injection of CO_2; c - dependence of the well flow rate on the injection of carbon dioxide from the expected discharge of the borehole; after injection of CO_2; d - dependence of the well flow rate on the injection of carbon dioxide from the expected capacity of the well in the known watering of the products.

The results indicate that an important role in the injection of carbon dioxide is played by indicators such as reservoir permeability and water content of products. We have received that the rate will increase almost twice, if the production of wells will not be watered, and if the well products are significantly watered, then we will get equal oil extraction after the injection CO_2.

3. Conclusions

It is known that very to be difficult to residual oil reserves of especially viscous and saturated water, and when the carbon dioxide is pumped out, which dissolves well into the oil, increases oil in volume and reduces the viscosity, on the other hand, dissolves in water, increases its viscosity. Thus, the distillation of carbon dioxide in oil and water leads to equalization of the mobility of oil and water, which creates opportunities for obtaining higher oil yields, both by increasing the displacement ratio and the coefficient of coverage of the oil deposit

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