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Research Article

The Coning Phenomenon and the Prevention Methods for one of the Iranian Reservoirs

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ABSTRACT
Water coning is the mechanism in which the water-oil contact locally rises toward the perforated interval in a partially penetrated oil well. The problem of water coming into an oil well impacts the well productivity and increases operate costs which in turn accelerates well abandonment. In this paper, various methods of water coning prevention such as water production from below of oil layer, injection of oil below production interval and creation of an impermeable zone around bottom of the wells for an Iranian oil reservoir were compared. It was deduced that the method of water production from below of oil layer is the best method for prevention of water coning in the specific oil reservoirs.

Keywords: Coning, Cresting, Critical rate, Breakthrough, water cut, Methods of water coning prevention, Effect of reservoir parameters on water coning.

INTRODUCTION
Water-gas coning phenomenon that indicates the mechanism of entry of water in lower parts of oil formations (aquifer) or available gas in gas cap to oil production wells is one of the most important problems in oil production wells that are prevalence in available wells and oil fields. This phenomenon occur when a high production rate is imposed to well and thus the factor that limits high production rate of oil from the well. Water-gas coning phenomenon is sensitive to high production rate and progresses only under certain equilibrium conditions.

Usually, in oil fields it is attempted that production rates controlled in a range that avoid entry of water or gas to oil producing well. When oil is extracted from drilled well in the reservoir, created gradient with capillary forces and wetting features caused that the mutual level of water and gas raised. Deviation of the mutual level of water and gas, mutually by gravitational forces as well as densities differences, is balanced. Due to the amount of these forces and which one of them could overcome another, the mutual level of water and gas may reaches a stable mode under the well which by passing of time caused simultaneous production of water with oil. Many studies have been done about coning phenomenon. These studies could be divided to two categories. The first studies that performed before 1970 and majority of them have been done on this phenomenon in vertical wells, and second studies that has been done after 1970. Due to the advancements of technology of horizontal wells, studies also conducted on coning in vertical and horizontal wells.

Another point of interest that is visible in studies is that studies of the first category are generally analytical and experimental and they are on vertical wells more while studies of second category are analytical and numerical due to the evolution of computers. One of the first studies about coning that sample reservoir engineering is recognized as the first studies was the study by Wyckoof and Muskat (1). They show for the first time clearly and through analysis that the phenomenon of water coning in evacuation of bid pressures. Although this study is done based on hypothesis like single-phase circuit, equal mobility relation etc. and reduces its functional use but this case is known as pioneer in coning. Later in 1960, Mushkat (2) considered accurately the pressure of wells that had faced with coning and studied the effect of factors like ratio of non-uniform $\left(\frac{k_v}{k_h}\right)$ on this phenomenon.

But about horizontal wells, one of the first studies was done by Efros in 1963. This study was performed when the technology of horizontal wells was still presented as a theory and technical curiosity. Also with another interesting and complete study about this phenomenon was done in lab laboratory scale. Also he used interesting innovation and gained the accurate amount of saturation and manner of motion of coning phenomenon by use of Archi relation. In the present research, also we try to consider the preventive ways of this phenomenon by simulator phenomenon.

Control and prevention ways of water/gas coning:

Prevention ways of coning are divided into to two general categories:

Ways of maximizing reservoir reserve and minimizing and delay of coning:

First category is the ways that were used for maximizing reservoir reserve and minimizing and delay of coning. This ways are related to time before the occurrence of the phenomenon and even well drilling. In other words, these operations are preventive cases as following:

Wells spacing:

Generally, even if coning is occurred in adjacent wells, however coning will produce water from produced cone for limit space and it is observed that if in adjacent wells in one reservoir, they arranged as their cones do not interfere with each other, better oil laver with more efficiency will evacuate from oil.

Completion interval:

According to conducted researches, recoverable oil by wells changes with cube of Standoff that defined as distance among fluid entry point from fluids impact surface. For this reason, one of the ways of reducing coning is optimization of this distance. Other available possible works are that the completion of well operated in a distance with higher porosity coefficient and high permeability and if this distance has a shield and cover from a hard layer, coning will be delayed more.

When dual coning is occurred, hence water and gas coning, both of them occurred, in this situation we should try break through time of two mentioned cases become equal that because of higher mobility of gas in relation to water it`s trying that completion interval is near to water impact surface and oil. As we know, the length of completion interval must be long enough to avoid drop of additional pressure in well spout. Also on the other hand this distance must be short enough to build proper Standoff, as previously mentioned. And this work should be operated with accurate consideration and attention.

Using horizontal wells:

From 1980 onwards, development of technology of horizontal wells caused that the resources and reservoirs with coning talented that were in margin or determined non-economic, gained importance again. Horizontal wells caused that fluid entry points were existed in longer distance that decreased the need to pressure evacuation. To evacuate low and long distances, horizontal wells can produce higher volumes of oil with economic production. Because standoff limits to pay zone, well radius and accuracy of excavation, these wells could be optimized.

The recoverable amount that is evacuated is proportional to length of horizontal well and also standoff. If some distances of evacuation area impact additional water or gas and they are detectable, they can be isolated and removed from circle. In some operations, wells are slightly titled to close the end of wells when water or gas entered. Given the above, we can say that horizontal wells could fix some current problems.

Reducing approaches of coning and their effects:

Second category is approaches that are used for reduction of coning and its effects. This category is related to time that the drilling and completion of well were finished and the well encountered with this problem. Several ideas are considered for this end. From presented approaches, the following approaches seem safer:

Limiting moving flow to well by using external material:

Injection of concrete materials, gels, polymers and/or foams:

If horizontal gaps can be created in standoff area, these materials will be used generally and widespread. In schematic figure in shape 1 that shows horizontal barrier in one reservoir, there are two unstable cones in the shape; one of them is depicted for radius of well spout and other for a horizontal barrier.

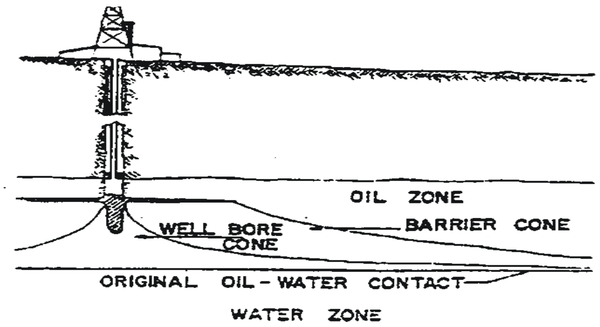


Figure 1: schematic approach of creation of horizontal barrier for prevention of coning phenomenon

For placement and installation of a horizontal barrier, this question exists that do a horizontal gap can be created or not? After ensuring from feasibility of this work, there are two ways for creation of barrier. The first way is that at first gap is created then filled with filling liquid and second way is that the gap is created by filling liquid.

Reduction of absolute permeability in standoff area by injection warp, Asphaltene etc.

Injection of oil to gas region, in other words placement of oil barrier against gas coning

The mechanism that is used here is reduction of permeability in relation to water and gas that the injection of oil to swept region is done by water and gas. The figure schematically shows a cross-section of region near well spout without oil injection.by oil injection above producing holes into swept region by gas, the cone gets away from well and caused Incremental sweep and increase of oil recovery. To this end, the completion region of well must be changed. One schematic figure of completion of this well showed in the figure.

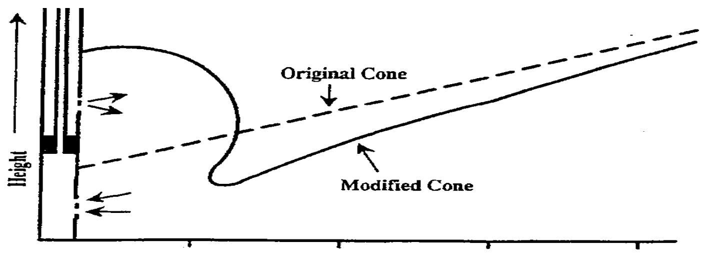


Figure 2: schematic of a cross-section of near region to well spout with/without oil injection

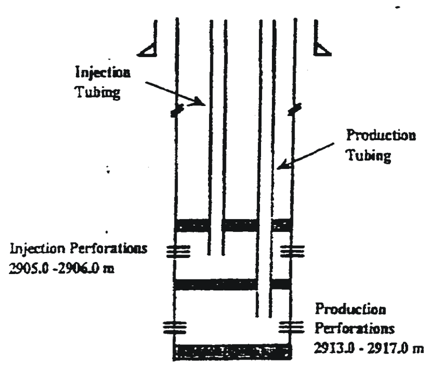


Figure 3: schematic of well completion, the approach: inject the oil again.

Also in schematic figure, well head equipment to inject again is represented. Produced oil form well passes a divider and part of this oil is separated and used to inject again.

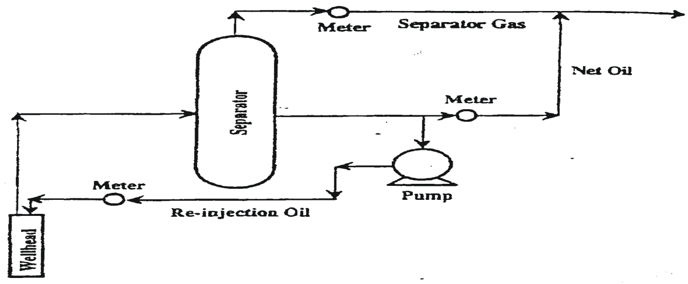


Figure 4: schematic of well head equipment to inject the oil again

Injection of chemical materials for reduction of relative permeability of water and gas

Use of chemical materials like gels, foams, polymers and washer materials for injection in water or gas region for reduction of relative permeability can be used in this approach.

Correction of pressure distribution around well:

Methods that fall into this category are:

Reverse coning: In this manner, oil is extracted in watery region to avoid coning of gas (and reverse). Gas tends to move to the regions that have more degree of water saturation and oil. Therefore, it encounters with additional resistance that is shown in the figure.

With this approach, the oil recovery can be raised to 15-30 percent but the amount of produced water also increased in this mode.

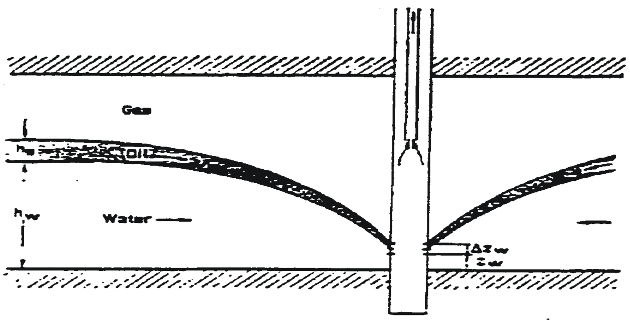


Figure 5: schematic of creation of reverse coning:

Creation of additional holes in watery or gas region:

This operation is used to correct distribution of pressure of around well spout and calm and reduce the coning in holes of oilfield that is shown in the figure.

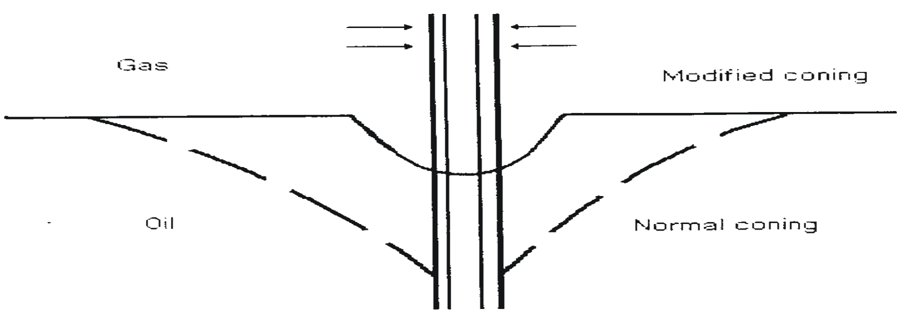
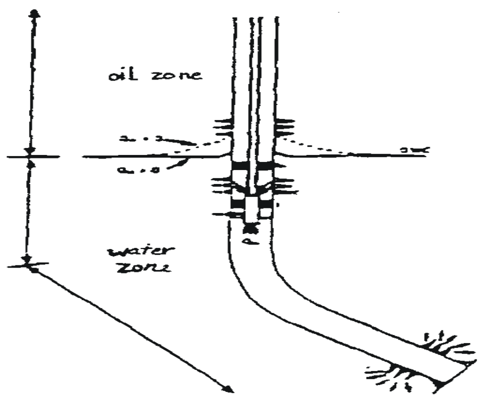


Figure 6: schematic of creation of additional holes in watery or gas region.

Separating bottom-hole of water and oil and injecting water again.

In this figure, as we observe, the swept pipe is used. Development of this approach depends on the economic aspect and its justification.



Depletion of watery or gas regions:

Of course this approach is considered only these regions have limit size.

In summary, technology of reducing and preventing from coning is in its first steps. Several approaches have failed in the scale of oil fields and presented disappointing results.

However, finding the approaches that are functionally and economically beneficial and justifiable must be placed in agenda.

Implementation of prevention ways of coning phenomenon by using simulator

Grid creation and preparation of data for simulator:

One of the most important parts of simulation is grid designing and geometrical shape of reservoir. For example, XY and XZ views of designed grid are used in simulation of intended reservoir in the figure. For sampling the thickness of layers, the thickness of layers is used. This grid is the kind of Cartesian Corner-Point. This grid consists of 157 columns, 40 rows and 9 layers. It should be noted that three first layers are the one geologically, but due to the grater thickness and better consideration, it is divided to three equal layers.

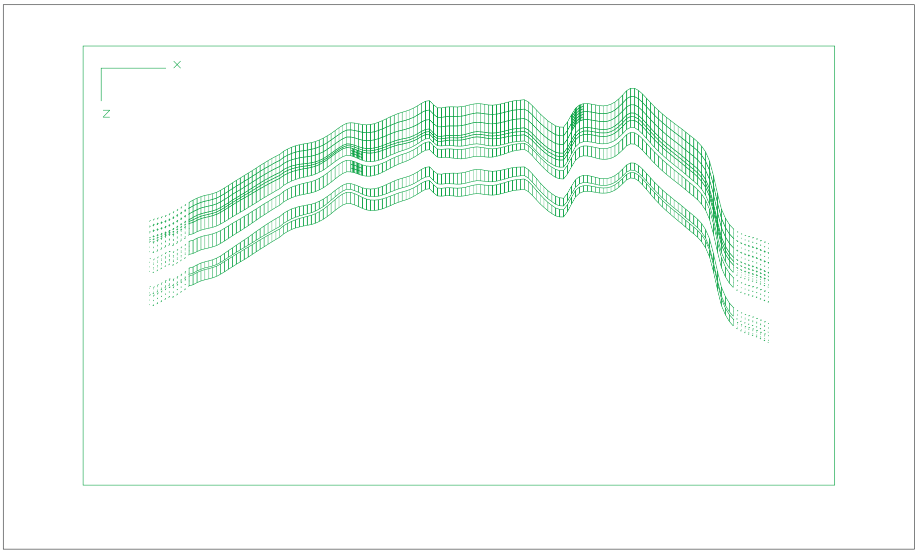


Figure 8: XZ view of designed grid for intended reservoir:

In regions under impact surface of water and oil, grids cells become inactive.

For accurate consideration of phenomenon around wells, LGR have been used. Studied reservoir has 13 wells that around openwork of wells, LGR is used.

In figure, XY view of grid with used LGR around one of the wells is shown.

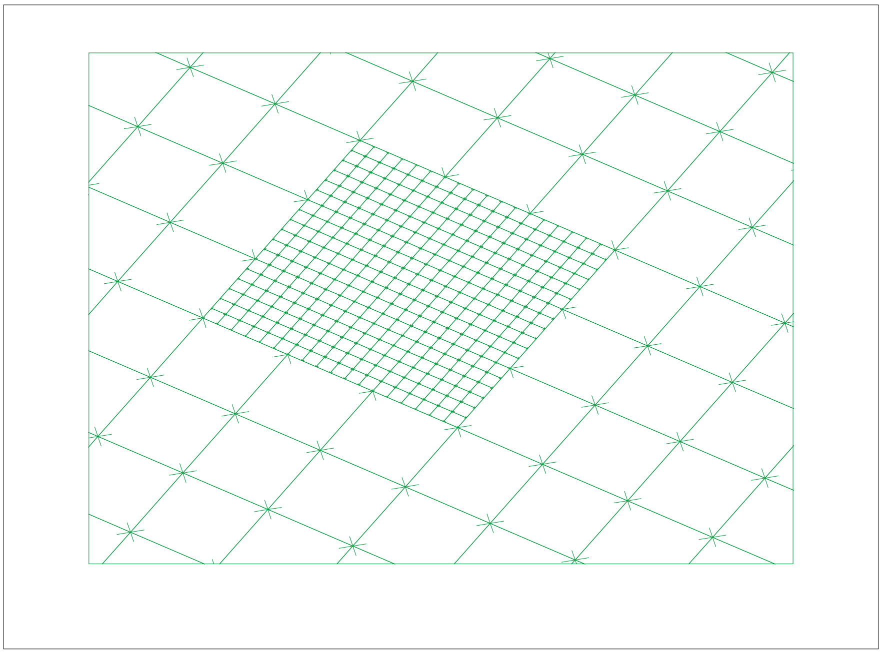


Figure 9: XY view of grid with used LGR around one of the wells

After finishing grid designing, all necessary properties for simulation (porosity, water saturation, and beneficial thickness to general) should be determined for each cell. This work is done by sampling of properties amounts from level maps of these properties. In this project, sampling is done by averaging of values in center and corners of each cell. For example, beneficial porosity maps, water saturation and thickness to general first layer are shown in the figures.

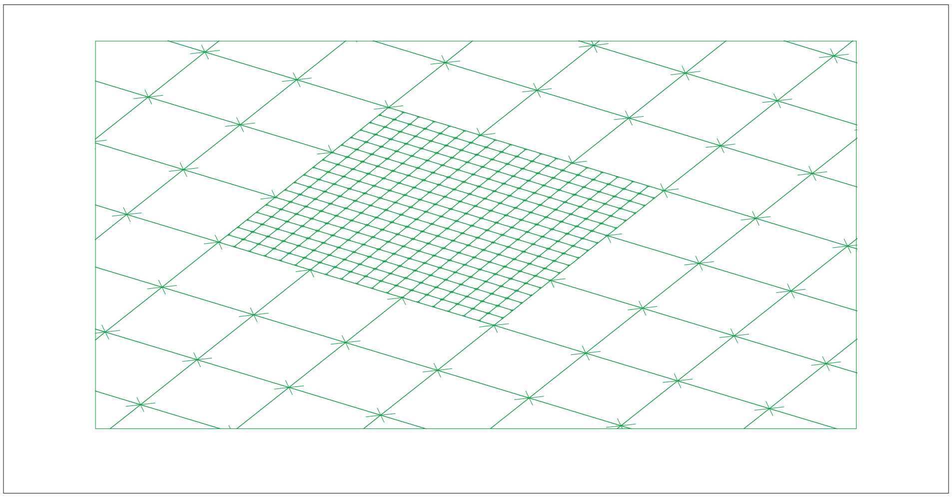


Figure 10: XY view of grid with used LGR around one of the wells:

After finishing grid designing, all necessary properties for simulation (porosity, water saturation, and beneficial thickness to general) should be determined for each cell. This work is done by sampling of properties amounts from level maps of these properties. In this project, sampling is done by averaging of values in center and corners of each cell. For example, beneficial porosity maps, water saturation and thickness to general first layer are shown in the figures.

After the above steps, geological model for using in simulator is ready.

To full simulation of software data, it is necessary that properties of reservoir liquids are determined in different modes.

PVT experiments are performed in reservoir features and well head in sampling time. Therefore, by using a simulator, properties of reservoir liquids, these properties are determined for different conditions and pressure for oil and intended reservoir water.

In studied reservoir, only one correct sampling case has been done in proper depth and in laboratory also full series of necessary experiments for table of liquid properties for oil model of simulator are done as follows:

1. Flash experiment at 135 F.
2. Differential expansion experiment at 135 F.
3. Differential expansion experiment at 215 F.
4. Viscosity experiment at 215 F.
5. Two phase Flash separator experiment.

The used software for thermodynamic modeling of reservoir oil is PVTi software. The used model equation is three parameters equation of Soave-Redlich-Kwong and equation of Lohrenz, Bray and Clark is used for prediction of viscosity. After predicting available experiments, differential expansion data at 215 F and flash separator experiment for producing output of software for 100 Eclipse were used.

Reservoir temperature in basic depth is at 201 F. at 215 F, the pressure of saturation point is 168 p that is 1595 p at basic depth temperature. Details of this output are shown in appendix 1.

Form other important data that is necessary for simulation data is relative permeability and capillary pressure. Because intended reservoir lacks special core analysis, to achieve this data we try as follows:

Relative permeability: nationality of relative permeability of water and gas are determined by the amount of saturation of wetting phase. To determine these parameters, the amount of irreducible saturation of water and gas phases is necessary. The amount of irreducible saturation of water and gas phases is achieved by using the results of petro physical evaluations. In any point of layer in which saturation amount of water fixes in a minimum and maximum value, we can calculate value of irreducible saturation of water and gas. In fact the minimum amount of water that remains stable in a layer is the amount of irreducible saturation of water. Now we can calculate the amount of relative permeability by following experimental relation.

$$k_{rwt} = (S^*)^{0.5} S^4_w$$

$$k_{rnwt} = [1 - \frac{S_w - S_{wi}}{1 - S_{wi} - S_{nwt}}]^2$$

$$S^*_w = (\frac{S_w - S_{wi}}{1 - S_{wi}})$$

:S_{nwti} Non-wetting irreducible saturation

:S_{wi} Wetting irreducible saturation

Mentioned relations are obtained by Pirson in imbibition mode. Therefore, by accessibility to Snwti and Swi, the nationality of relative permeability could be obtained from saturation amount. Of course as it was mentioned, these relations are experimental and do not show the real habit of reservoir. But it should be mentioned that according to reservoir history, for example based on existence of production problem of water, they are corrected.

To determine capillary pressure in any layer, following relation is used:

$$P_c = (g_w - g_o)(depth - woc)$$

Depth: depth by m

GW: special weight of water by (N/M3)

Go: special weight of oil by (N/M3)

Woc: contact surface of water and oil by m.

First, capillary pressure is calculated against the amount of water saturation for any well in any region. In this phase, data from the amount of water saturation in front of depth that is resulted from Petro physical is used. For one of the main oil layers in data of relative permeability and capillary pressure of that layer against each other, table 1 is prepared and curve of relative permeability for that oil layer are depicted in figure 2.

Table 1: relative permeability data and capillary pressure for one of the studied oil layers of reservoir

S_w	k_{rw}	k_{ro}	P_c
0.28	0.000	0.991	6.9280
0.30	0.000	0.991	6.4261
0.32	0.000	0.985	5.9670
0.34	0.000	0.960	5.5454
0.36	0.000	0.936	5.1571
0.39	0.000	0.911	4.7981
0.41	0.000	0.862	4.4653
0.43	0.000	0.819	4.1559
0.45	0.000	0.770	3.8676
0.47	0.000	0.720	3.5982
0.49	0.005	0.654	3.3459
0.51	0.009	0.600	3.1092
0.53	0.011	0.525	2.8867
0.55	0.015	0.440	2.6771
0.57	0.020	0.346	2.4793
0.60	0.025	0.193	2.2924
0.62	0.030	0.132	2.1154
0.64	0.040	0.080	1.9477
0.66	0.055	0.046	1.7885
0.68	0.065	0.027	1.6371
0.70	0.070	0.000	1.4931
1.00	0.250	0.000	0.0000

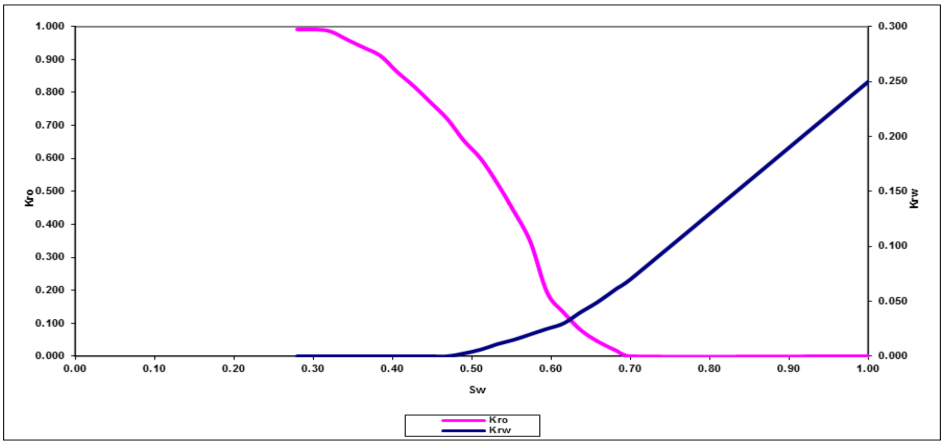


Figure 11: curve of relative permeability for one of the oil layers of reservoir

After creation of geological model and determination of reservoir liquid properties, simulation enters to next steps.

Drilling of horizontal well for prevention from coning phenomenon:

According to advancements of technology in drilling of horizontal wells, today in oil industry, there is special attention to this subject. As previously mentioned, in horizontal wells because of great length of them, the created depletion pressure will be low that as a result caused that coning phenomenon occurred later than vertical wells. To consider the effect of horizontal well, in model of vertical well 3, it is converted to horizontal well that its final depth was equal to final depth of well 3 in vertical manner. The length of drilled well considered as 390 m. in figure, the amount of achieved water section for two modes are depicted. As you see, in horizontal well, in addition to lower amount of water section, coning phenomenon also has occurred later.

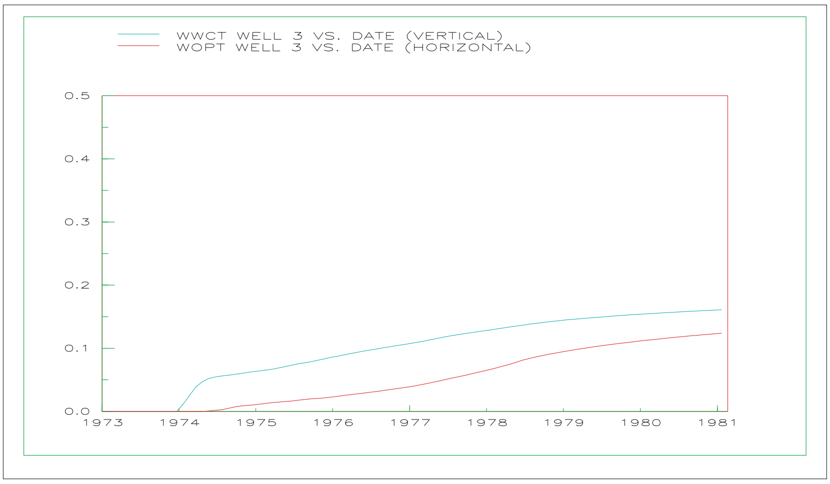


Figure 12: achieved amount of water section for vertical and horizontal well

Now after consideration of approaches, it is necessary to compare them. To do so, it`s necessary that the condition of oil production equals for all approaches, so in all of them the value of oil production of well 3 was considered as 10000 STB/D. in figures 18 and 19, the amount of water section and production of water of well 3 for different approaches are depicted. In the approach of oil injection to below production region for prevention of coning phenomenon, because of injection of parts of produced oil, so this approach was done in two modes, in one of them, it is considered that the total of production and injection of oil equals with 10000 STB/D (the amount of production as 13500 STB/D and injection value as

3500STB/D)and in second mode as all other approaches, we considered production as 10000 STB/D and injection was done by previous production rate. Due to the deterministic role of final production rate for these approaches, so for comparison of approaches with each other, we consider first mode. Of course it should be mentioned that in the approach of drilling of horizontal well, because the kind of well is changed, we can`t compare it with other approaches, but as you see, it has effective role in delaying the coning phenomenon but in production from these wells we must be careful that cone do not reaches to well spout. If this case is happened, the amount of water section will increase suddenly.

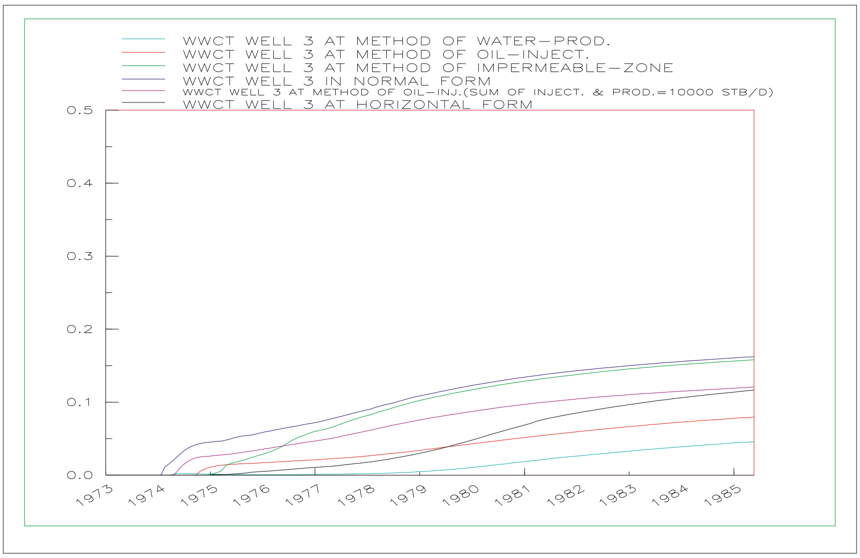


Figure 13: the achieved amount of water section for different approaches with similar condition

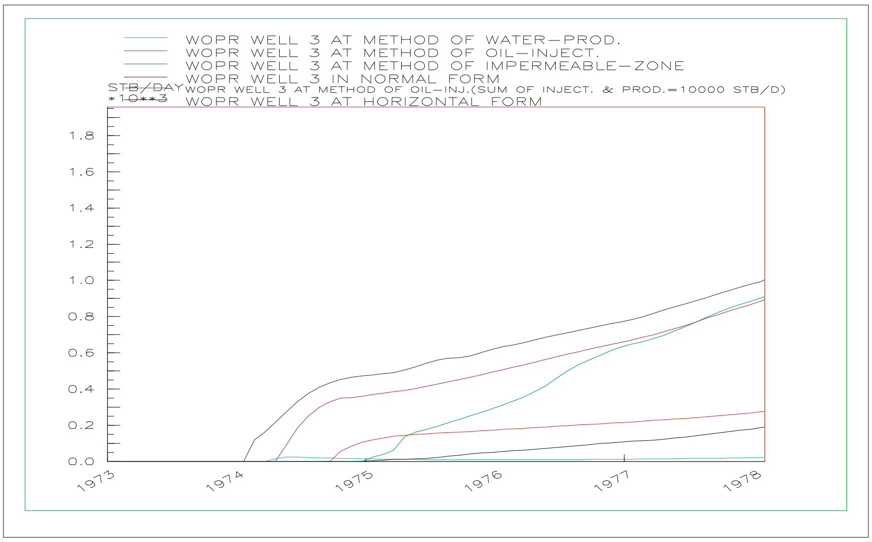


Figure 14: the achieved amount of produced water for different approaches with similar condition

As it is observed in figures, among these approaches, the best result is production of water from under oil layer for prevention from coning phenomenon.

For considering that if in studied reservoir preventive approaches from coning phenomenon are used, how will affect oil production, water section amount, the amount of cone progress and reservoir pressure, by using the approach of water production from under oil layer and suitable production as 2500 STB/D, the model is operated. To consider the effects, we can compare this comparison with reservoir history. We can result that operation of prevention ways from coning phenomenon, in addition to increase of oil production, also helps to maintain the maximum daily production that is utilized from well during utilization period which we have lager scope in the case of economic need and also fluctuation of world price of oil. For example, if in production period after 1980 we need higher production from well 3, the amount of water section will not permit, because all surface equipment are not enough for this separation of water section. Also the amount of water section will increase during the future years.

If during operation with prevention approach we have relative scope, we will increase oil production and also increase the production of water with it to avoid creation of cone.

RESULTS:

The main results of this research could be classified as follows:

1. Whatever produced rate is fewer and near to critical rate, coning phenomenon will occur later.
2. In producing water form under oil layer, whatever water rate is further, we can control coning phenomenon better.
3. The approach of inscrutable region creation is only effective in delaying coning phenomenon and after cone can pass this region, the amount of water section will like water section mode without this region.
4. In the approach of oil injection under production region, whatever injection rate and injection distance from production region are further, and its effect will be further in controlling coning phenomenon.
5. Among prevention ways form coning phenomenon, in special condition, the approach of water production from under oil layer has the best effect in control of coning phenomenon in comparison with other approaches.
6. In reservoirs, we must try to prevent coning phenomenon because in the case of occurrence of this phenomenon, prevention approaches will have fewer effect.
7. In horizontal well, in addition to fewer amount of water section and later occurrence of coning phenomenon, critical rate will be further.

Suggestions:

1. In this project, prevention ways from this phenomenon are considered that for future works, economic consideration and study of these approaches will be beneficial and choose the best way by consideration of this subject.
2. Prevention ways from coning phenomenon could be considered for cloven reservoirs and simulated.
3. Due to this fact that in near future reservoir pressure get to the point under saturation point and as a result gas cap forms, so consideration of coning phenomenon about reservoir that has Gas cap and aquifer is necessary.
4. Due to the vertical permeability effect in creation of water coning phenomenon, we can study about the injection of gel to region under well in this reservoir and simulate that.

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