Abstract

During the oil production in mature fields, the implementation of water flooding projects plays an important role for increasing the oil production and the recovery factor of the reservoirs, and this is the case of the Golfo San Jorge Basin in Patagonia Argentina (GSJB). This basin, located in the central Patagonia (Figure 1), is the oldest productive basin of Argentina where the first economic discovery took place in 1907 in Comodoro Rivadavia. With 13,973 active oil wells (Jun 2016), Golfo San Jorge is the first oil producer basin of Argentina producing 251,000 bpd of oil (49% of Argentinian oil production) and 3,2 MMbpd of water.

The total of water produced are injected in 3,140 wells used for water flooding projects, where 46% of the oil is produced from this method. The continued implementation of these projects, in company with the drilling of new wells, incorporate water from the reservoirs to the production systems continuously introducing various technical, economic and environmental challenges. As part of a comprehensive water management strategy this paper describe different process and operative considerations, as the result of 109 years of production in the oldest basin of Argentina. The following topics will be addressed:

- Water production and management in Golfo San Jorge Basin
- Water treatment and distribution (Surface and subsurface)
- Water flooding projects trends
- Water balance: Bottlenecks Analysis
- Water management cost and how affect the total operational cost
- Well integrity management
- Artificial Lift challenge's, among others
As results it is mentioned the important of to take the decision for manage water during the development of fields. Many challenges arise during the production of a mature field with high volumes of water, but is important to understand about the need not only to do it, but also to have and to apply a field operation model to extend the life of mature fields.

Finally, real statistics, information about facilities, best practices and recommendations, are presented with the objective of provide a guide for developing similar fields.

The Golfo San Jorge Basin

Geological description
The East-West trending Golfo San Jorge basin is the oldest and most prolific oil basin of Argentina It covers 28,000 M Acre, with 1,127 MMbo (Dec-05) of OOIP and is in the central Patagonia.

The first commercial oil discovery took place in 1907 and since then close to 2,900 MMBOE were extracted. Located in the central part of Patagonia Terrain, it is an intracratonic extensional basin. During late Jurassic-early Cretaceous times, the extension related to the Gondwana break-up generated many isolated small half-graben basins, with a NW-SE structural trend. Later, a new extensional-transtensional stress field originated a WNW-ESE trending, and reduced extensional deformation continued until the Oligocene.

The basin is essentially asymmetric; in the eastern section the dominant extensional faults are on the northern flank with the southern flanks being a less faulted, flexural type margin. In contrast, the western section is asymmetric but its major faults are on the southern flank, being the northern flank a flexural margin. The central section of the San Jorge basin is dominated by NW and NNW trending extensional faults that were reactivated by compression in Tertiary times (Figure 2)
The main characteristics of this basin are:

- Faults and sandstone lenses
- HWOR (high water-oil ratio)
- Increasing fluid flow rate per well
- Complex fluids: corrosive, heavy oil, gas, sand and scale
- Multiphase flow
- Multilayer reservoir: from 1,800 to 9,000 feet
- Vertical wells (5 ½" casing)

**Well completion**

Related to the wells production, all of them are exploited with artificial lift systems (ALS). From the beginning of oil industry in GSJB, several ALS's have been used to produce the wells. Now, systems as Sucker Rod Pumping (SRP), Progressing Cavity Pump (PCP) and Electric Submersible Pump (ESP) are the most popular systems used to produce the total basin fluids, and smaller quantities of hydraulic jet pump (HJP), plunger and gas lift systems (GL) are used.

ALS's are distributed as follows: 10,253 SRP; 2,035 PCP and 1,474 ESP. Close than 90% pumps are installed between 3,000 ft and 8,000 ft depth, producing flow rates over 1,500 bpd. Deeper target reservoirs and wells with higher flow rates mean a permanent challenge for the different ALS's and specialist involved.

**Water production and management at Golfo San Jorge Basin**

The production history of the GSJB could be said to be associated with water production from the beginnings, although in recent years the volumes have been increasing.
The Graph 1 represents the history of oil and water production of the GSJB since 1999 to date which reflects the efforts to increase and maintain the oil production from producing more and more volumes of water, with the implication that this represents both the costs of production and the maximum capacity of management of the water produced.

![Graph 1—Oil and water production history](image)

When we talk about Water Management, we say the objective is to maximize the value of the assets by increasing oil production, the reserve recovery factor, and reducing the production cost and practically canceling the environmental impact (Figure 3)

![Figure 3—Objectives of water management](image)
**Water production, treatment and distribution**

Managing production water involves different activities which are mentioned below:

- Production
- Treatment, distribution and injection
- Subsurface distribution
- Integrity control of the injector wells as well as surface installations

In terms of production, the water associated with oil is collected in production batteries and transferred to treatment and injection plants (Figure 4). In some cases, the water is separated in these facilities and derived to treatment plants. Once in the treatment plants, the water is conditioned and distributed through pumps to the water injectors wells.

![Figure 4—Typical water production and distribution scheme](image)

Below are mentioned some of the most common equipment and techniques used for the separation and treatment of injection water:

- FWKO or free water tanks for water separation
- Skimmer and sedimentation tanks for suspended solid and oil removal
- Suspended solid removal by filtration
- Dissolved gas removal (oxygen, H2S, CO2) by chemical treatment
- Scale prevention by chemical treatment
- Slime and bacteria control by chemical treatment
- Corrosion control by chemical treatment
About to the distribution of water, there are about 3,140 injector wells (Figure 5) that distribute the 3.2 MMbpd of water produced, which is used as an energy source for secondary recovery projects by water flooding.

For the water injection, multi stages centrifugal pumps at the injection plants and at the booster unit are used in most of the cases, and reciprocating pumps are used in small projects.

Field manifolds are used for the distribution, flow rate regulation and measurement of the water injected in each well. During the last years, electromagnetics flowmeter has been used as well as SCADA systems for surveillance the injection process (Picture 1)

In terms of flow regulation, this allows the injection rate to be kept constant, independent of the available pressure. If the system pressure increases, the regulator opens allowing the same fluid flow rate to pass with a lower differential pressure. If there is an increase in the injection pressure, the regulator will close automatically until the desired flow is maintained. In GSJB are used mainly two types of regulators:
• Downhole regulators valves, housed in the mandrels in depth of the well, and
• The surface ones that are used in some projects

**Downhole Distribution**
According to the number of reservoir to be injected, selective installations may have:

• a simple installation with surface flow regulation,
• or a multiple installation with bottom flow regulators, to individually control the injection by reservoir.

Due to the multy layers characteristics of the reservoirs, the injection can reach up to 19 reservoirs in the same well using selective injection. The types of selective injection installation that exist in the GSJB can be grouped into 3 items, depending on the type of packer's tandems used:

• Mechanical Installations
• Hydraulic Installations
• Mixed Installations

As previously mentioned, downhole regulator valves housed in the mandrels in depth of the well, are used for flow rate regulation.

**Waterflooding projects in GSJB: the key for water management**
The GSJB presents hundreds waterflooding projects, distributed in areal and vertical form. Regarding to the percentage of production participation by different recovery, 46% of the total production of oil is from secondary recovery, 53% by primary and 1 % from EOR. (Graph 2). With respect to oil production from the EOR, we could say that it is incipient but will be key to increase the oil recovery factor and improve the efficiency of the sweeping of the injected water. Accompanying this evolution, we find that the percentage of water currently reaches 92.7% with an incremental rate of 0.3 % per year during the last 6 years (Graph 3).
Water balance: Bottlenecks Analysis

The production and management of water in the GSJB basin should not only be interpreted as the management of a waste, but as the source of energy for the maintenance of oil production. But in any case, the management capacity of the same, from the operational point of view must be evaluated permanently since in many fields, the inability to manage this water implies loss of oil production.

For this reason, the water balance as well as analysis of the bottlenecks is fundamental, to maintain the production of oil and to evaluate the maximum capacity of water management from the technical and economic point of view. But what happens when we reach the maximum limit of water management capacity? Figure 6 represents the different stages during the water handling process which will serve to analyze the different actions to reach the maximum capacity of water management.
When the limit of water handling is reached, we can consider at least two options, to reduce the water production and/or to increase the water collection (increase the stations capacity), treatment and injection, but in both cases a technical and economic analysis is required.

About restrictions that could affect the water injection, we can mention:

- Low injectivity at the reservoir
- Collection, treatment and distribution capacity limited
- Environmental issues
- Economic limits
- Limit of artificial lift systems affected to produce well from waterflooding projects

From the water source point of view, some actions could be considerate:

- Water shut-off
- Insolate water zone (some time oil production is insolated too)
- Shut-in producer's wells (the last decision)

and from the water handling and injection point of view:

- Injector Wells stimulation (increase injectivity)
- Well conversion (producer to injector)
- Improve the treatment and transportation capacity
- Modification of patterns of injection
- EOR projects implementation (increasing of the recovery factor)

But in all cases a continued review of the developed plan is required.

**Water management cost: How affect the total cost?**

During the production of mature fields with high percentages of water, we could say that the costs associated with the production are directly related to the production of water. Another aspect to highlight is that as the percentage of water increases, the cost per barrel of oil will increase as shown in *Graph 4*
About the distribution of production costs and taking as an example a mature field in GSJB, at least 28% of the lifting cost of production is directly related to the management of produced water, where 25% of this cost is associated with the energy consumption as shows the Graph 5.

Well Integrity Management
Due to the Environmental Security Regulation, it is necessary to guarantee a perfect mechanical integrity in injector wells, this means to obtain hermeticity in the Casing-Packer-Tubing system, between the top Packer and well-head, during the operative life of the well.
The injector wells in the Golfo San Jorge Basin are subjected to extreme variations of operative conditions (pressure and temperature), which cause premature failure in assembly. The objectives of the well integrity management for injectors Wells are:

- Protect the fresh water zones
- Control the surveillance of the repaired injector wells
- Ensure the control of annulus pressure (second barrier)

In this order, the IAPG (Argentine Institute of Oil and Gas) Sectional Sur, through its Technical Commission, has developed a Recommended Practice, applicable to injector wells for Assisted Recovery, in areas where there are aquifers of interest, suitable for human and/or agricultural consumption, and/or for irrigation. To verify and monitor the effectiveness of the three barriers that normally exist in each injector well, as described below (Figure 7) and to avoid contact of injection fluid (treated formation water) with freshwater aquifers.

The main objective of this practice is to have a working methodology that allows at all times the life of the injector well, to ensure that at least one of the barriers is protecting the freshwater aquifer. It also defines the basic guidelines to:

- Apply an adequate methodology of monitoring and diagnosis
- Ensure early loss detection.
- Propose an action plan for the control of such losses
Artificial Lift Challenges

During the production water management process, artificial lift systems are the first sub-process associated with it, and can be critical at advanced stages during the mature fields operation. As previously mentioned in the GSJB, not only does the percentage of water increase but also the flow rate, which means that the requirements for higher flows per well are increasing.

If we consider the restriction of the casing diameter, and the increasing flowrate and pump depth per well, the maximum power transmission from the prime mover to the pump is a common factor on the three more important systems as Progressing Cavity Pumps (PCP), Sucker rod pumps and Electric submersible pumps (ESP). To enhance this capability has been requested a combination between new materials, design and operational condition.

Sucker Rod Pumping: The use of high-strength sucker rod and premium connections, have been a common practice during the last years. The use of the long stroke pumping units is other new practice that will allows reaching more flow rate and depth, to reduce the dynamic loads.

Progressing Cavity Pumping: As the SRP system, the use special sucker rods have been one of the most important practices. The hollow rods, high-strength rods and premium connections, have allowed to increase close to 100 % of the torque transmission in 27/8" tubing if we compare with the most common sucker rod, 1" API Grade D.

For increasing the flowrate capacity of the pump, the last trends have been to increase the volumetric displacement in pumps, increasing the stage length and reducing the eccentricity of the rotor. In addition, RPM over 500 RPM is a common practice in shallows wells (3,000 feet depth). Respect to elastomers, the new developments have been associated to increase the millions of cycles of deformation, before fatigue (hysteresis)

Electric Submersible Pumping: The equipment's with TR3 series Motor (with shroud and below the perforations) have reached the capacity of the TR4 series Motor, despite its reduction in shaft and coupling diameter. The main reason of this has been the continuous modifications, new designs and new technologies applied by the main ESP service company in GSJB.

Conclusions

In mature fields, sometimes the water control is not an option, and it's necessary to produce water for producing oil.

- Investment in treatment facilities, distribution and injection will be required.
- A continue water balance a and surveillance is important for improving the oil production
- Continue lifting cost analysis is required in mature fields.
- EOR projects implementation could be an option for improving the recovery factor, but it will depend on the return on investment (EOR projects can have long-term results).
- Team work between Production, Reservoir and Facilities Engineering and Production Operations is necessary for developing and monitoring water flooding projects, and managing the water distribution.
- Improving the Water Management Process, we can Increasing the Asset Value and extend the life of the mature fields.

Nomenclature

- BPD = barrels per day
- EOR = enhanced oil recovery
- MMbpd = millions of barrels per day
MMBO = millions of barrels of oil
MMBOE = millions of equivalent barrels of oil
OOIP = original oil in place

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