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Mechanical Water Shut-Off Strategy on Multilayer Tubingless Wells of Offshore Mahakam Field: JM-X Success Story

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Abstract. The objective of this paper is to present the Mechanical Water Shut-Off (MWSO) strategy for multilayer reservoirs on tubingless well. With 10 open perforated reservoirs and no selectivity option, isolation on water producing reservoir will be the main challenge since production is commingled throughout the lifetime of well. Regular production tests performed through a Multiphase Flowmeter equipment on each offshore platform is a first indicator to monitor the evolution of water production in a well. JM-X well has been experiencing water breakthrough since one week after initial perforation and WGR keep increasing following gas production decline. The strategy was initiated by conducting a bottom hole monitoring survey to identify water sources. Production Logging Tool (PLT) was used to precisely monitor pressure, temperature, water holdup, and fluid rate along the wellbore for further water source and production allocation analysis. Once the water source reservoirs have been identified, MWSO operation was requested. There are several types of MWSO equipment that are commonly used in Offshore Mahakam field each of which has selective economic consideration based on the expected well reserve. Considering operation difficulties and cost, MWSO program was made then will be monitored during the operation time to ensure the operation runs safely and smoothly. MWSO strategy on well JM-X was proven to be able to reduce water production from 900 bpd to only 20 bpd with a significant gain of gas production from 3 MMscfd to 9.2 MMscfd and oil production from 200 bpd to 750 bpd.

Keyword: MWSO, WGR, water production, multilayer, tubingless

1 Introduction

South Mahakam is a gas field located in the Offshore Mahakam at East Kalimantan – Indonesia with water depths of 40-60 meters and 35 active wells located on 4 production platforms. The production from this field was started at the end of 2012, with peak production of around 350 MMscfd in 2015. The current gas production of the field is 85 MMscfd with CGR around 50 bbl/MMscf and WGR around 100 bbl/MMscf.

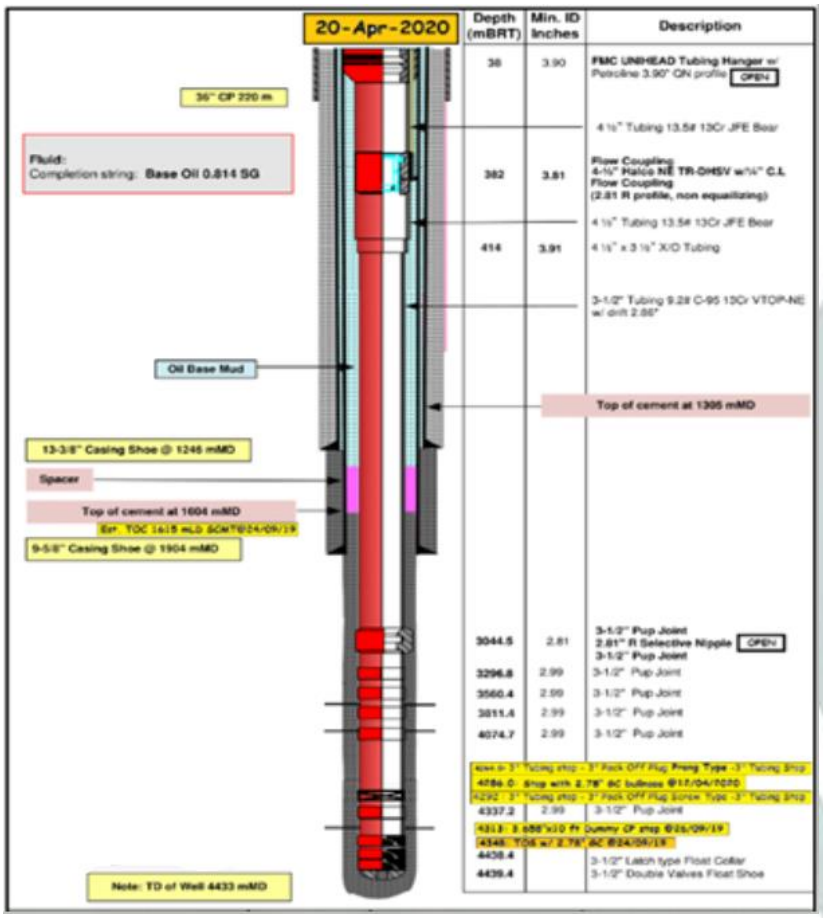


Figure 1. Tubingless completion with perforation in South Mahakam

South Mahakam well typically is between 3300 – 4000 meters subsea total depth with 20^0 – 57^0 inclination. A tubingless completion is the standard well design with a production tubing size of 4.5” or 5.5” as depicted in **Figure 1.** With more than 10 open perforated reservoirs and no selectivity option, isolation on water producing reservoir will be the main challenge since production is commingled throughout the lifetime of well.

Ensure production continuity by water shut-off operation in this multilayer well is very crucial to secure reserve. Water Shut-Off (WSO) operation has been performed for hundreds of well in

Mahakam offshore fields with typical two available types of jobs: MWSO (Mechanical Water Shut-Off) and CWSO (Chemical Water Shut-Off). Between the two types of WSO jobs, MWSO is the most frequent selected type by considering the economical aspect. Despite economic advantage, MWSO has several drawbacks, such as tubing inner diameter's (ID) reduction or blockage that could prevent further intervention job, isolation length limit for single perforation of only 6 meters with casing patch, and tool setting difficulty on high dog leg severity wells. On the other hands, these drawbacks create an opportunity for the other type of WSO to be used.

2 Methodology

2.1 Water production monitoring of South Mahakam Field

Water breakthrough is a serious problem for reservoir properties and production deliverability. In a multi-perforated well, high water production from one of the reservoirs can increase pressure losses alongside the production tubing and decrease well productivity. Over time, reservoir pressure depletion will lead to insufficient pressure drawdown to produce gas and lift the water from the well. This phenomenon will lead to a liquid loading issue. Within a long period waiting for production maintenance or well service operation, the water column can damage the other gas-producing reservoirs in contact. As the production is commingled throughout the lifetime of this multi-perforated layer well, interference among the zone or water crossflow to depleted gas reservoirs can also worsen the damage to the reservoirs leading to well production decrease. The liquid column inside tubing also creates scale deposition alongside the production tubing that has been found on other wells in the Mahakam Offshore field that require either mechanical or chemical washing to restore well productivity. Moreover, for such a long period, production tubing corrosion for numbers of well have been encountered that lead to a serious problem for well integrity issues. Surface facilities problem created by excessive water production is adding backpressure to the network that can also reduce gas production from the other wells.

Water source identification need to be done before performing any water shut-off operation. Regular production tests performed once-per-week through Multi-Phase Flow Meter (MPFM) located on each platform provide gas, condensate, and water rate measurements. This test becomes the first indicator to monitor the evolution of water production in a well. To differentiate whether water production is coming from gas condensation or the reservoir, water to gas ratio (WGR, bbls/MMscf) value becomes a good indicator.

In South Mahakam, wells are initially only producing gas and condensate. Once water production is detected, it is considered a water breakthrough problem thus several production tests will be requested to closely monitor this high WGR value. Additional data acquisition also needs to be carried out to identify the water source. Currently, there are around 5 wells with a WGR > 50 bbls / MMscfd and water rate around 700 bbls/day.

To precisely identify the water source reservoir, further data acquisition need to be performed. For South Mahakam wells which typically have more than 10 commingled producing reservoirs, water source identification from one of these reservoirs becomes a challenging task. Downhole data acquisition by using the Production Logging Tool (PLT) will be used to fulfil this task. In each of South Mahakam wells, regular production logging operations are performed around once a year for wells for production allocations, pressure data, and liquid source detection. However, these production loggings are performed more frequently for wells with water production problems to identify water sources prior to isolation

PLT in South Mahakam wells is typically run with pressure, temperature, density, capacitance, and spinner measurements. The water production problem zone is identified by analysis of tool reading results showing the turbulence effect of the high water inflow, higher density, higher temperature, and the contrast capacitance reading compared to the other producing gas reservoirs.

2.2 Available Water Shut-Off Means

With water source data identified by PLT, WSO operation then is requested to isolate it as soon as possible. Since the start of Mahakam Field production in 1974, water zone shut off operation, either with mechanical or chemical has become a routine for thousands of well. MWSO is preferred to be carried out over CWSO because of lower costs and simpler operation. There are several types of MWSO equipment that are commonly used in the Mahakam field. Based on the capability to allow fluid flow from below setting depth, it can be differed to Bridge Plug and Casing Patch.

Bridge Plug (BP) isolates the water source located below the setting point. This technique will allow neither gas flow from below the reservoir nor further downhole well service operation below the setting depth. Based on retrievability, BP **(Figure 2)** is available in permanent and retrievable types. Permanent Bridge Plug can be set either by Slickline or Electricline. However, a comprehensive study needs to be done before setting the permanent BP as no future well intervention operation allowed for a reservoir below the BP setting depth. BP milling operation needs to be executed to re-entry the reservoirs below BP setting depth which will generate additional cost. Meanwhile, Retrievable Bridge Plug (RBP) that can be set by Slickline or Electricline can be retrieved by Slickline or Coiled Tubing. However, RBP that has been set for such a long period in a well might be difficult to retrieve.

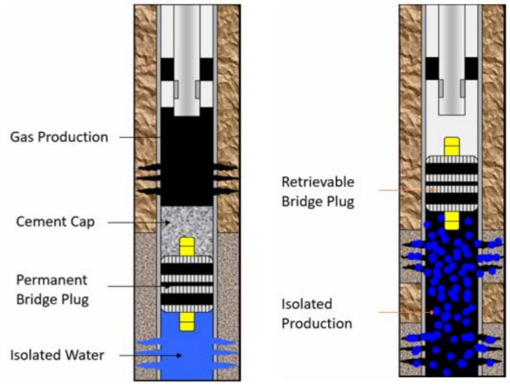


Figure 2. Permanent Bridge Plug (left) and Retrievable Bridge Plug (right)

Based on packer element expansion mechanism, BP **(Figure 3)** is divided into mechanical and inflatable Bridge Plug. Mechanical Bridge Plug (MBP) can be set by Slickline or Electricline and can also be retrieved by Slickline or Coiled Tubing. It is available as a permanent or retrievable plug on the market. MBP has also lower cost than Inflatable Bridge Plug. However, its packer element expansion range is not as wide as Inflatable Bridge Plug that will not allow the BP to pass through small ID (casing patch, nipple) and set to larger setting ID. Several types of Mechanical BP can pass through Casing Patch ID, but it needs additional cost for dump cement operations as per manufacturer recommendation thus considered as permanent plug. Meanwhile, Inflatable Bridge Plug (IBP) that can be set by Electricline or Coiled Tubing can also be retrieved by Slickline or Coiled Tubing. IBP is available in permanent or retrievable plug on the market. It allows a wider range of packer element expansion but offers a higher cost than Mechanical Bridge Plug. For a well with high dog leg severity, Coiled Tubing is the only means to deploy the IBP.

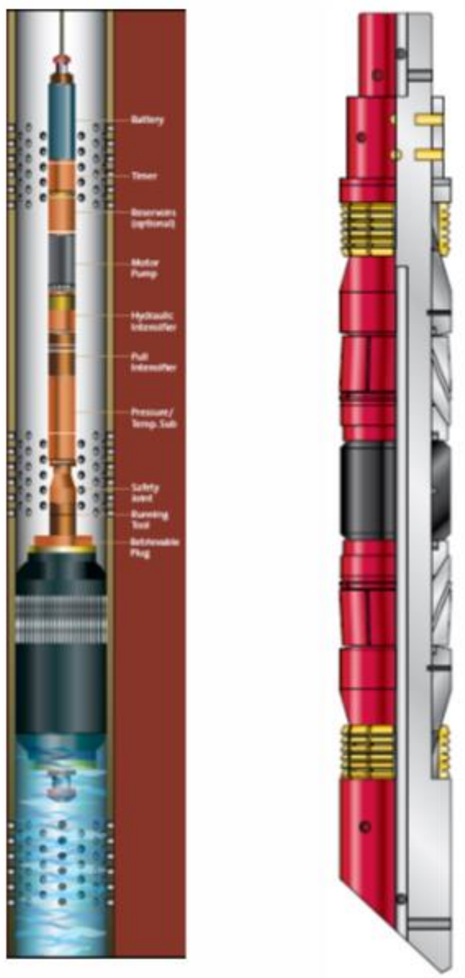


Figure 3. Inflatable (left) and Mechanical (right) Bridge Plug Illustration

In most cases, there are still gas reservoirs that need to be produced below the water source which will be isolated. Therefore, Casing Patch **(**CP, **Figure 4)** that allows fluid flow from below the reservoir is preferred zone isolation method. CP also allows future well intervention operation below the setting depth such as PLT or additional perforation. Zone isolation for the below-CP-setting-depth's reservoir also still can be done by using IRBP for retrievable option and MRBP for a permanent option. However, Casing Patches also come with several limitations to prevent the use of this equipment. The first limitation is that CP is permanently set in a well so that perforation of the same zone is the only way to re-produce the zone in the future. The second limitation is dog leg severity in highly deviated wells that will not enable CP to pass through the setting depth of this section of wells. The third limitation is the maximum perforation length that can be isolated by CP is 20 ft due to Pressure Control Equipment (PCE) length limitation.

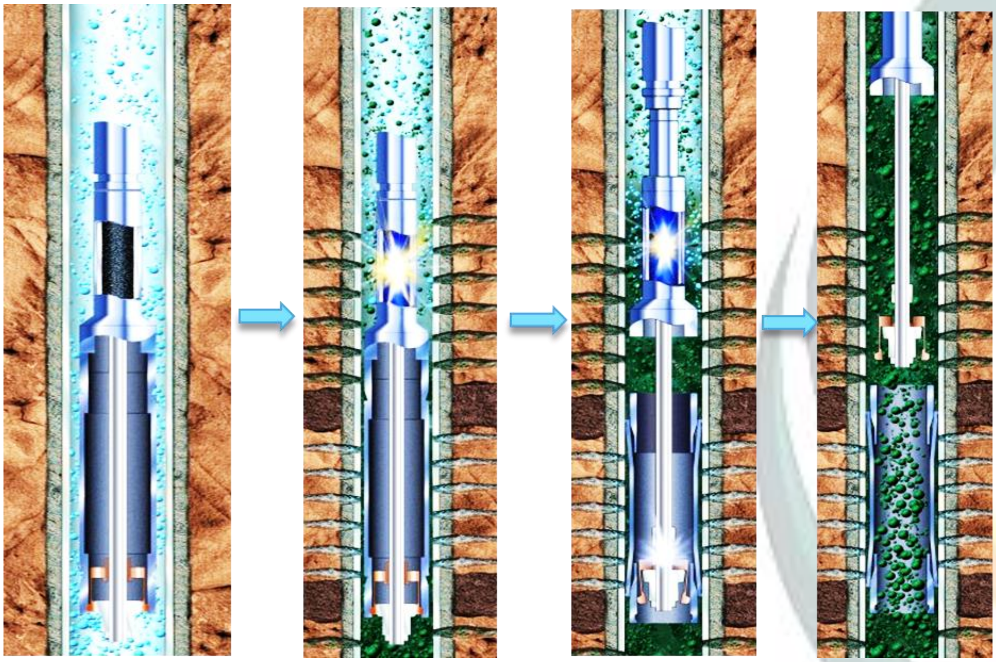


Figure 4. Casing Patch Illustration

Since the MWSO solutions have several drawbacks, the CWSO study was launched in 2004 with the first trial for 3 wells has been conducted in 2007. In the period 2007 to 2018, the CWSO job is executed for 13 wells. CWSO jobs are executed in 11 wells to isolate the water source that is located in the uppermost section of 25 – 60 multi-perforated layers which still allows further production and well intervention jobs for the below-setting depth section. Meanwhile, for the other 2 wells, CWSO is executed to shut off the Sliding Sleeve Door (SSD) that cannot be closed and isolate leak slightly above the SSD. With a cost ranging from 10 – 20 times higher compared to MWSO, the success rate ranges from 0-100% in terms of gas, oil, and water rate difference before and after shut-off.

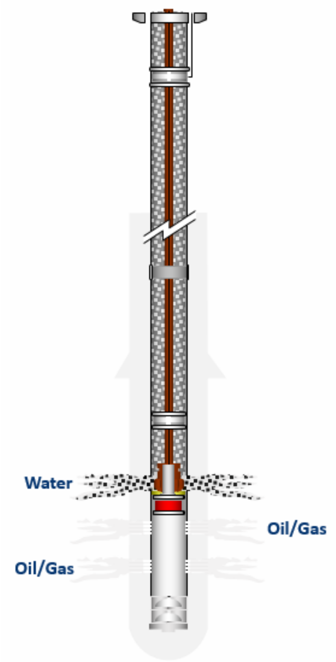


Figure 5. Chemical Water Shut-Off (CWSO) Illustration

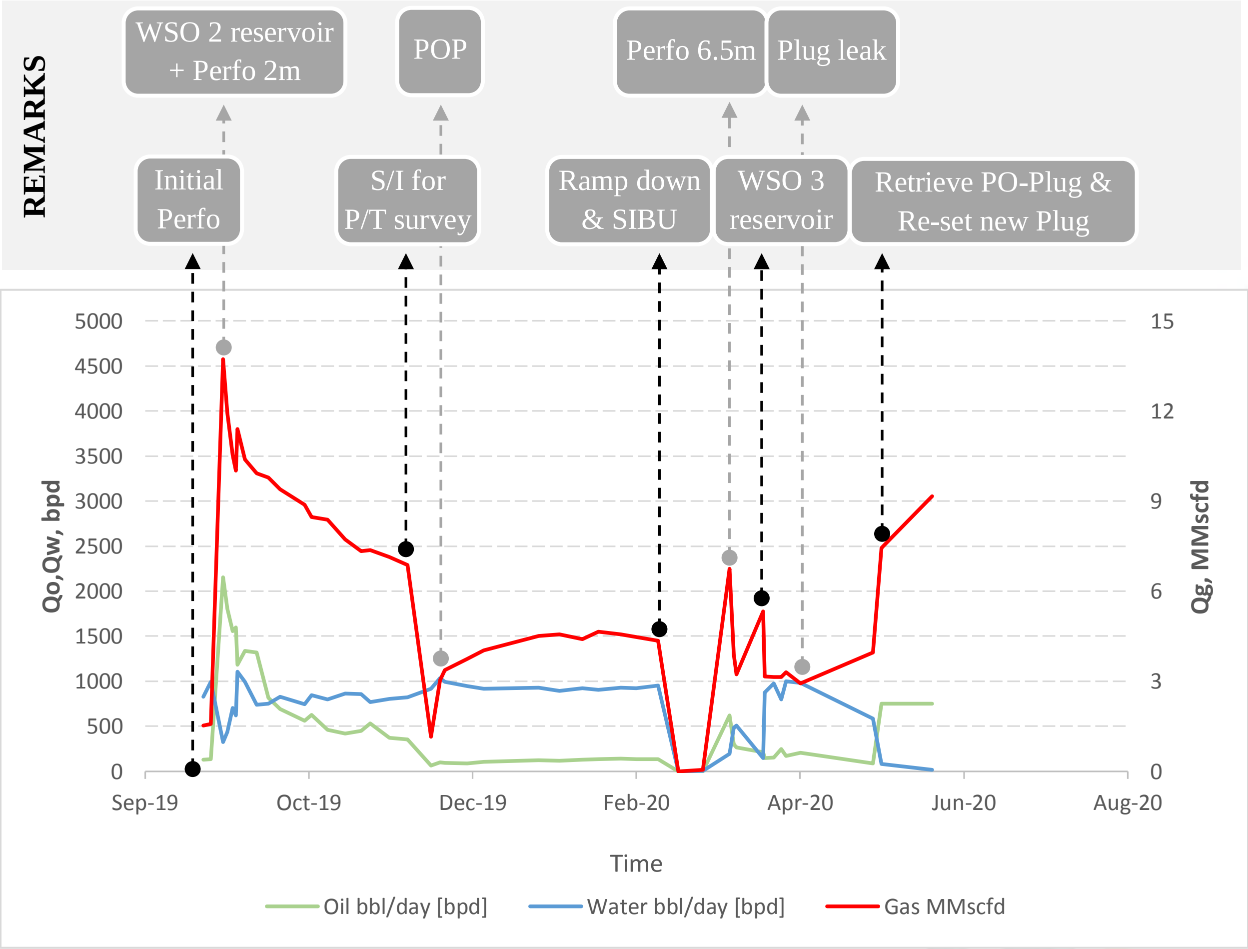
3 Result and Discussion

3.1 Mechanical Water Shut-off operations on well JM-X

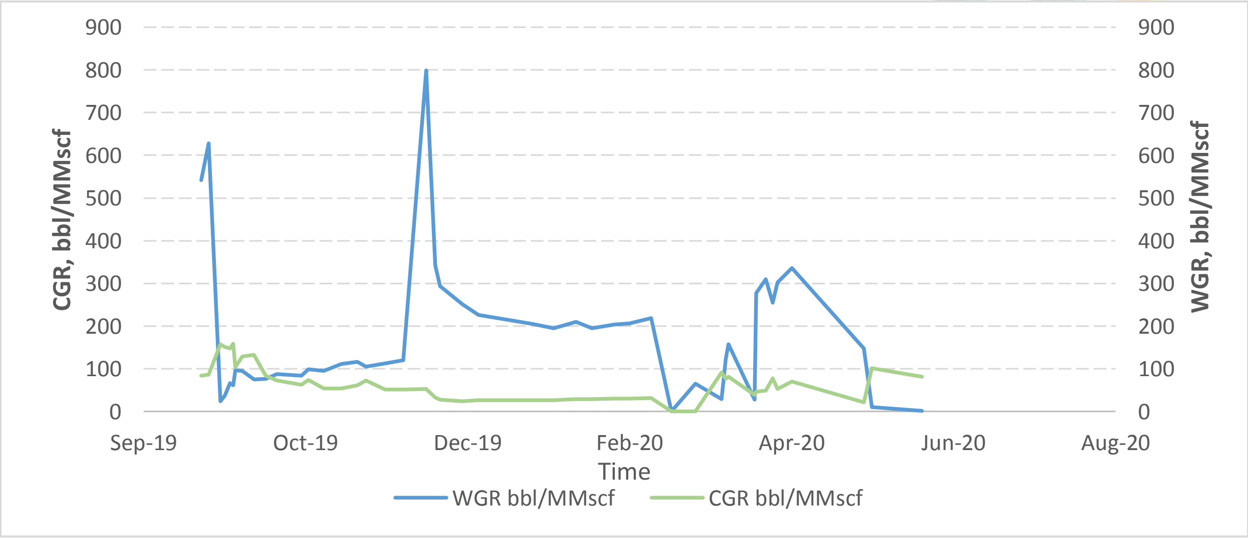
JM-X is a new well in JM platform of South Mahakam Field. The well was completed with 4-1/2" tubingless completion (Figure 1). The first well intervention job objective was to perform CBL/VDL and initial perforation in September 2019. Perforation Batch#1 for 5 reservoirs (Table 1) with a total interval of 13 meters had been performed and this well produced 13.7 MMscfd gas.

Table 1. Perforation Batch#1

Reservoir	Top Perf	Bottom Perf	Perf Length
	m MD	m MD	m
aJ1	3775.1	3778.1	3
	3783	3786	3
J2	4180.7	4181.7	1
J3	4278.2	4280.7	2.5
J4	4305.3	4306.3	1
J5	4309.6	4312.1	2.5
		total	**13**



Graph 1. Production rate profile well JM-X



Graph 2. Water and Condensate to Gas Ratio well JM-X

Production logging performed after initial perforation found that reservoir J4 and J5 produce a high water rate. By considering that only 3 perforated zones would be left open, MWSO was selected compared to CWSO. With several zones of interest below the bottommost perforated zone, it was proposed to set Pack Off (PO) Plug, a retrievable plug, at 4292 meter measured depth (MD). Perforation Batch#2 of reservoir J6 and J7 (**Table 2**) above PO Plug's setting depth was executed afterwards to increase well production.

Table 2. Perforation Batch#2

Reservoir	Top Perf	Bottom Perf	Perf Length
	m MD	m MD	m
J6	3802.8	3803.8	1
J7	3824.7	3825.7	1
		total	**2**

After 2 months of production, gas rate was declining to 7.4 MMscfd with 534 BCPD and 771 BWPD. Hence, the second well intervention job was executed in December 2019 to increase gas production and isolate water source reservoirs. A production logging job was performed to determine the water source target and followed by MWSO job directly after interpretation to isolate the water source. However, the production logging survey could not detect water sources due to unstable bottom hole condition, it was concluded to perform production logging survey with longer stabilization period on the next campaign.

The third well intervention job was executed from March to April 2020. Production logging was proposed to be performed again with longer shut-in and flowing duration to get better information on water sources. The job sequence started with perforation Batch#3 (**Table 3)** on high-pressure reservoirs followed to and continued with production logging & WSO. Production logging result on April 2020 indicated that water source was coming from below PO plug indicating that the PO plug was leaking. Therefore, another PO plug was set at 4264 mMD to isolate the water source and leaking plug. However, based on production test, the water rate remained the same. Then, with another production logging performed, it was found that the PO plug was still leaking despite having 2 PO Plug on top of each other inside the wellbore. With the last production test data result of 3.3 MMscfd, 237 BOPD, and 1122 BWPD, 2 PO Plug was proposed to be retrieved and replaced with SIM Plug, another type of retrievable plug with lower risk of leaking history. The production test was then performed and show good results of water production decrement from 900 bpd to only 20 bpd with a significant gain of gas production from 3 MMscfd to 9.2 MMscfd and oil production from 200 BOPD to 750 BOPD.

Table 3. Perforation Batch#3

Reservoir	Top Perf	Bot Perf	Perf Length
	mTMD	mTMD	mTMD
J8	3093	3095	2
J9	3104.5	3107	2.5
J10	3687	3689	2
		total	**6.5**

4 Conclusion

Regular production test and followed by PLT measurement proved to be reliable to monitor and determine the water source before the water shut-off operation. Years of experience in Offshore Mahakam field provide many choices that can be executed to solve water breakthrough problems in a multi-perforated layer of tubingless wells. Mechanical Water Shut-Off (MWSO) strategy on well JM-X was proven to be able to reduce water production from 900 bpd to only 20 bpd with a significant gain of gas production from 3 MMscfd to 9.2 MMscfd and oil production from 200 bpd to 750 bpd.

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