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Low Salinity Water Injection North Mahakam Sangasanga Field Case Study

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Abstract. North Mahakam Sangasanga is one of the mature oil fields in onshore Kutai Basin, East Kalimantan.The field was discovered by NIIHM – a Dutch oil company in 1897. The field comprises over 100 hydrocarbon accumulations in deltaic sands. Hydrocarbon accumulations are found at depths as shallow as 100 mSS and continue down to 1800 mSS. Low Salinity Water injection has been performed since 2008 with an extraordinary results. The paper intends to describe the success story of this secondary recovery by low salinity water injection application in North Mahakam Sangasanga field main zone, which has successfullyincreased the oil recovery.

The water from shallow reservoirs is produced with electrical sub-submersible pumps or sucker rod pumpsand directly pumped into the water injection network connected to water injector wells with a wellhead pressure of 250 psi. The water injection rate is 300 to 2500 bwpd from 54 active water producers. The water production and injection rate evolve over time following the reservoir management practice and well-producer availability. Currently, this water injection is resulting in oil production of 1700 bopd.

Monitoring and observation of the performance of water injector and oil producer wells are performed daily. Wellhead data is regularly checked and recorded. On the reservoirbasis, monitoring has been done regularly by controlling the material balance of the reservoir by creating VRR so that water injection allocation and injection recommendation can be regularly updated., Some reservoirs are expected to have oil recovery up to 40%. A progressive development plan embraced this excellent result. Following the success story, an ongoing development studyon the low salinity water injection application is initiated for 6 selected reservoirs in North Mahakam Sangasanga Field.

Keyword(s): Low Salinity, water injection, mature field, oil recovery

1 Background & Objective

North Mahakam Sangasanga is one of the mature oil fields in the onshore Kutai Basin, East Kalimantan, divided into three areas: Anggana, South Kutai Lama (SKL), and North Kutai Lama (NKL), shown in Figure 1. The field was discovered by NIIHM – a Dutch oil company, in 1897 and started producing in 1903. More than 100 hydrocarbon layers in the North Mahakam Sangasanga, which the drive mechanism mainly solution gas drive and a combination of a solution gas drive and a water drive with an Estimate Ultimate Recovery is 18% to 36%.

North Mahakam Sangasanga field is located at one of several culmination structures along the anticline crest, which is asymmetrical, elongated and oriented in the NNE-SSE direction, with hydrocarbons accumulating within 100 mSS to 1800 mSS, with an average reservoir property of porosity. 21% to 32%, Swi 35% to 55%, permeability 150 mD to 1100 mD, temperature 45 deg C to 86 deg C.

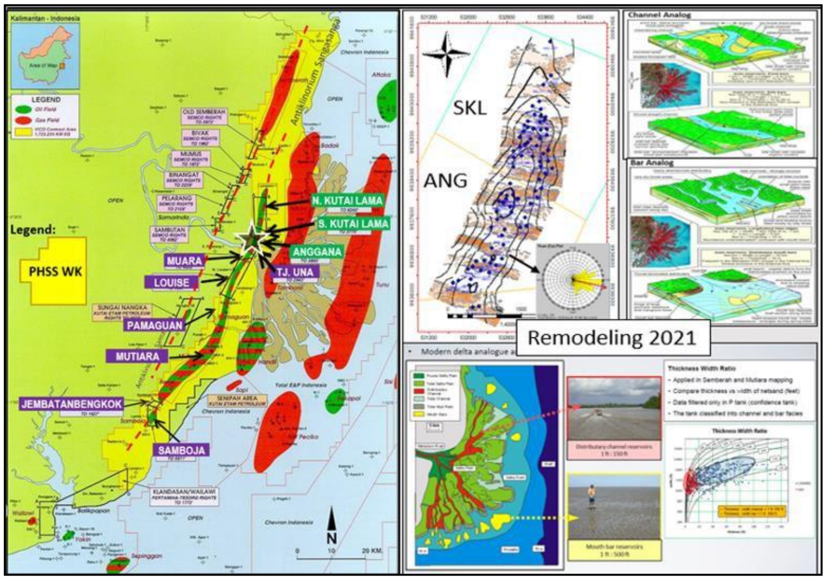

Figure 1. North Mahakam Sangasanga Field Area

Based on the petrographic study of the North Mahakam Sangasanga field shown in Table 1, there is the presence of clay in productive formations with clay percentage of 16.2%. Mineral clay consists of 52% kaolinite, 12% chlorite, 22% illite, and the remaining 14% mixed-layer clay.

Table 1. Petrographic Study of the North Mahakam Sangasanga

Estimate of Net Percent Clay Minerals: 16.2

Mineral	Percent of Sample Analyzed	
Quartz	67	
Feldspar	06	
Pyrite	04	
Siderite	07	
Kaolinite	08	52
Chlorite (Fe-rich)	02	12
Illite/Mica	04	22
Mixed-Layer Clay*	02	14
TOTALS	100%	100%

Water injection in the North Mahakam field has been going on since 2008 into hydrocarbon layers as part of water management. The injected water comes from produced water in shallow wells. The injected water has a salinity of 525 ppm to 1100 ppm, and a TDS of 3250 ppm to 4500 ppm (shown in Table 2) is classified as slightly saline water (shown in Table 3).

Table 2. Water Injection Analysis

WATER ANALYSIS -- STIFF METHODE

Ion	mg/l	mgeq/l	% react, value
Natrium Na+	629.31	27.36	25.85
Calsium Ca++	100.00	5.00	4.72
Magnesium Mg++	249.28	20.50	19.37
Karbonat CO3=	75.00	2.50	2.36
Bikarbonat HCO3-	2135.00	35.00	33.07
Sulfat SO4=	20.41	0	0.40
Chlorida Cl-	532.50	15.00	14.17
Besi, Fe+++	1.19	0.06	0.06
Total dissolved ion	**3742.69**	**105.85**	**100.00**

NaCl, mg/lt	: 2436.53	pH	: 7.500
Free CO2 mg/l	: 0	Suspended Solid	: not measured mg/l
SI (Scale Carbonat)	: + 0.35 → Scale	Dissolved Solid	: not measured mg/l
Scale Sulfat	: No Scale	Oil Content	: not measured mg/l
Water tendention	: Scalling	Turbidity	: 112.00
Resistivity , ohm-m	: 2.20	PRC	: not measured mg/l
Total Hardness	: 71.63	Specific Gravity	: 0.000

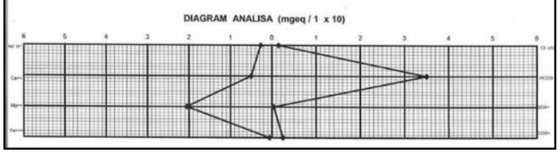

Table 3. Water Salinity Classification (source: FAO irrigation paper 48 1992)

Water class	ECw (dS/m)	Salt concentration (mg/l)
Non-saline	< 0.7	< 500
Slightly saline	0.7 – 2	500 – 1500
Moderately saline	2 – 10	1500 – 7000
High saline	10 – 25	7000 – 15000
Very high saline	25 – 45	15000 – 35000
Brine	>45	>35000

Based on the reference summary of Norman R. Morrow (2012) and Bigdeli (2016), several conditions cause the sweeping of low salinity injection to be run optimally, including:

- The presence of clay (kaolinite)
- There are divalent cations in the formation of water
- The reservoir temperature is below 130 deg C
- Low Salinity brine (affected yield up to 5000 ppm)

Based on these data, the North Utara Mahakam field meets the criteria for optimal sweeping using low salinity injection.

2 Methodology

The methodology of reaccessing hydrocarbon layers which is affected by low salinity injection are:

- Building Low Salinity Water Injection database

  Because so many oil companies worked to develop North Mahakam field, it created an improper database due to missing lots of data. Building the Low Salinity Water Injection database started by recapitulating the perforation data of injection wells and injection rates to obtain water injection cumulatively. Injection at the North Mahakam field started in the Anggana Area in 2008, which is usually carried out in large hydrocarbon layers that are no longer potential. The results of the injection recap show that the total volume injected in Anggana is 74 MMbbl, SKL is 2 MMbbl, and NKL is 41 MMbbl.

- Building Production Well Database

  It was recapitulating the perforation data, layer names, initial and last production records and cumulative production of each layer. The analysis was conducted to evaluate the potential for reactivation of low salinity injection layer located in suspended wells and active producing wells and to check the condition of these wells to be candidates for Workover and Well intervention wells.

- Low Salinity Injection Analysis

  Performing analysis on water injection layers that have received injection responses based on pressure increases or production gain responses from reactivation of wells that previously had been abandoned because they were considered unattractive. In addition, the calculation of VRR (Voidage Replacement Ratio) also needs to be done to determine the effectiveness of the injection. The Voidage Replacement Ratio is the ratio between the volume of fluid injected and the volume of fluid produced. (Ahmed, 2001). If the value of VRR is less than 1 (VRR<1), then the injection rate is not optimal and must be increased for production optimisation. However, if the calculation results show that the cumulative VRR is more than 1 (VRR>1), then the injection rate is optimal enough so that the oil production rate can be optimized to increase

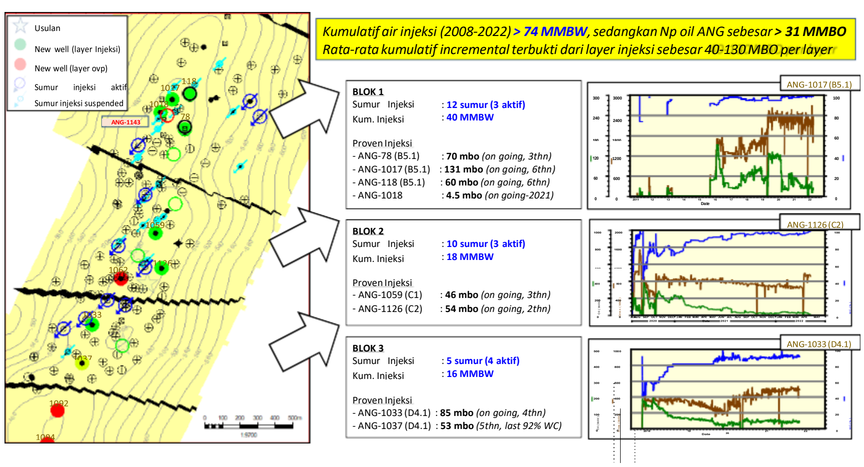

Figure 2. Example of Low Salinity Injection Analysis in Anggana Area

- Create a Workover, Well intervention, or drilling program

  Making proposals for candidate wells that have the potential for workover and well intervention programs targeting low salinity water injection layers that have received injection responses.

Calculate cost estimates, the scope of work, estimate production forecast and well economic calculations.

3 Well Intervention Layer EK Case Study

The EK layer is a depletion drive reservoir with a reservoir containing clay (kaolinite) which was produced primarily in NKL from EK-01 to EK-05 from 1977 to 2016 (suspended in the period 1978-1995) with Np 1.28 MMSTB or RF 36 % and the development concept from downdip to updip. The wells producing the EK layer will be suspended if the water content reaches 98%, and the EK layer will be totally suspended in March 2016 due to the increase in water content. In addition, there has been a decrease in reservoir pressure from 840 psi to 348 psi.

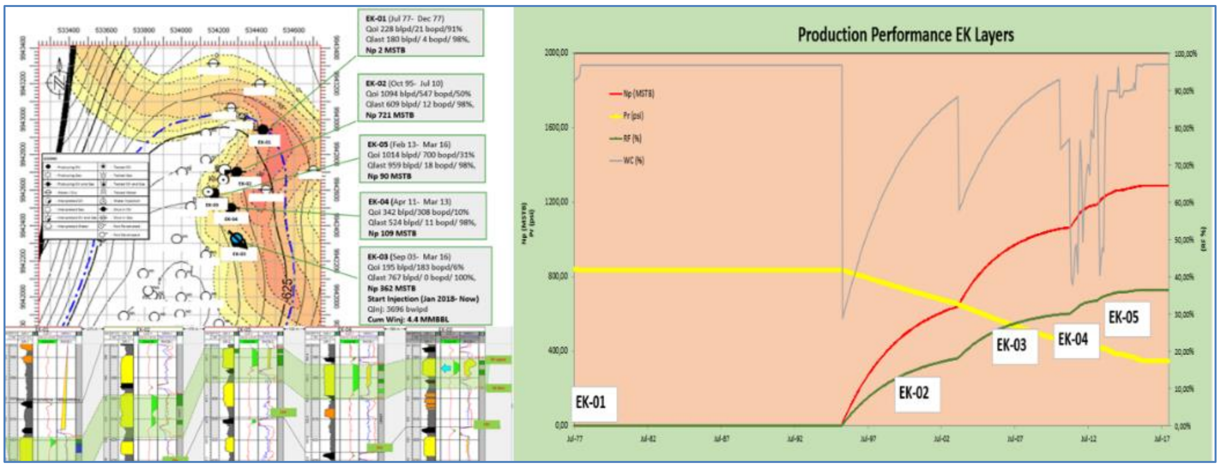

Table 4. Correlation and Injection performance of EK Layer

To reactivate the EK layer, a low salinity injection is needed in the EK layer with a target rate of 2400 blpd for 4-5 years so that the VRR approaches 1. The EK-03 well is converted from a production well to an injection well considering the southernmost position (sweeping is expected from south to north) and ready for surface facilities. Since January 2018, water injection has been carried out in the EK layer from the EK-03 well. The average injection rate is 2500 blpd, THP 196 psi, and a total injection of 4.4 MMBBL. Based on the recalculation of the recovery factor using the JJ Arps equation, an Estimated Ultimate Recovery Factor increased from 37.26% to 40.86% after injection or an increase in reserves of 0.13 MMSTB[tp1]. Reactivation has been carried out in the EK layer at EK-05 as a result of an increase in production from Qlast March 2016 by 18 bopd to 188 bopd when reactivated in July 2022 and an increase in Pres from 348 psi to 800 psi. Based on the reactivation results, there is also the potential to be carried out in EK-02, which is in a more downdip position.

		Sebelum Injeksi	Sesudah Injeksi
Tank		108	108
Interval (m)		550-625	550-625
Temperature	deg.C	56,8	56,8
Pi	*psia*	840	840
Boi	*v/v*	1,08	1,08
µoi	*cp*	1,20	1,20
µwi	*cp*	0,46	0,46
Ø	*fraksi*	0,32	0,32
Sw	*fraksi*	0,41	0,41
k	*D*	0.2 - 1.4	0.2 - 1.4
Estimated Ultimate RF	%	37,26	40,86
T. sep	*deg.R*	545,7	545,7
	deg.F	86,0	86,0
OOIP	*MMSTB*	3,53	3,53
EUR	*MMSTB*	1,32	1,44
NP	*MMSTB*	1,28	1,29
Reserves	*MMSTB*	0,04	0,16

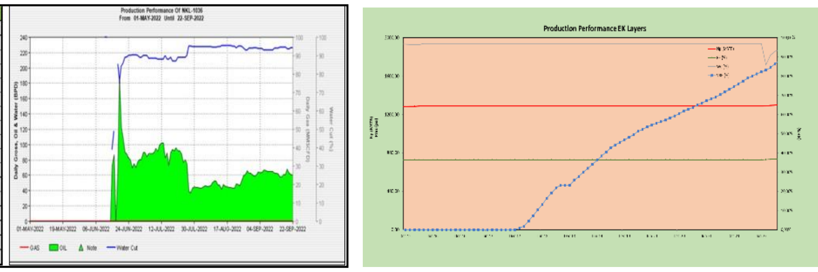

Figure 3. JJ Arps Recovery Factor Recalculation after Low Salinity Injection on Layer EK

4 Drilling Candidate Case study

After recalculation of potential layers and re-checking the accessibility of each layer which has the potential to increase recovery due to water injection, three new drilling candidates were found in the Anggana Area. This new drilling candidate is based on the large number of layers affected by injection in Anggana and the difficulty of accessing wells due to poor well integrity (84% of Anggana's wells were drilled before 1946).

NO	Zone-Tank	Type	Topsand (m SS)	Netpay (m)	Estimate Pressure (psia)	Estimate Pressure (ppg)	Por	Perm (mD)	Inplace Volume (MMstb) 2P	Production Cumulative (MMstb)	Production 2P RF	Production 2P ROIP	Inc. Reserves (MMstb) 2P	Inc. Reserves 2P Final RF	Expected Rate (BOPD)
1	B-3	O	154	1	208	0.95	0,30	180	0,75	0.024	3%	0,7	0.005	4%	16
2	B-4	O	193	2	271	0.99	0,30	180	0.22	0.005	2%	0.2	0.005	5%	16
3	C-2	O	409	3	576	0.99	0,29	450	6,14	0.129	2%	6,0	0,037	3%	125
4	D-1	O	496	3	724	1.03	0.28	375	7,13	1.715	24%	5,4	0,032	24%	67
5	D-7.1	O	768	3	550	0.50	0.24	66.5	0,41	0.050	12%	0,4	0.010	15%	21
6	D-10	O	915	4	1330	1.02	0.20	13	0.57	0.083	15%	0.5	0.015	17%	40
			Total	14											
	Estimated TD		940	TVD m SS							OIL MAIN (MMSTB)		0.102		
											OIL ALL (MMSTB)		0.104		

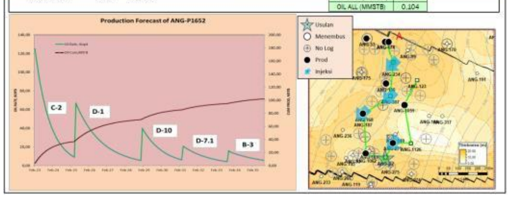

Figure 4. Drilling Candidate in Anggana Area

5 Conclusion

- Low salinity injection in the North Mahakam Sangasanga field increases the recovery factor from 3% to 7% in proven oil-producing layers.

Layer	Area	OOIP (MMSTB)	Np (MMSTB)	EUR Before Injection (MMSTB)	EUR Factor Before Injection (%)	Injected Reservoir (MMSTB)	VRR	EUR After Injection (MMSTB)	EUR Factor After Injection (%)	Increased RF (%)
BH	Anggana	4,34	0,78	1,19	28%	6,62	1,17	1,5	35%	7%
CL	Anggana	8,16	0,41	1,66	20%	4,36	0,49	1,88	23%	3%
BL	Anggana	7,13	1,77	2,2	31%	9,01	1,05	2,58	36%	5%
BY	Anggana	5,23	1,23	1,57	30%	3,46	0,66	1,74	33%	3%
EK	NKL	3,53	1,28	1,32	37%	3,63	1,03	1,44	41%	4%

Table 5. Recovery Factor Increase of Low Salinity Injection Layers

- Production gain from 25 bopd to 188 bopd after workover and well intervention program executed in layers affected by low salinity injection in the North Mahakam Sangasanga field from 2021 to 2022.

Sumur	Waktu Pekerjaan		On	Qoi			
	Mulai	Selesai	Producti	Oil	WC	Np (MSTB)	EUR (MSTB)
WOWI 1	15-Apr-21	21-Apr-21	20-Apr-21	64	92%	17,4	50
WOWI 2	12-Aug-21	17-Aug-21	17-Aug-21	79	90%	7,2	27
WOWI 3	26-Dec-21	31-Dec-21	31-Dec-21	44	97%	7,0	33
WOWI 4	7-Jan-22	14-Jan-22	14-Jan-22	96	86%	1,9	8
WOWI 5	20-Feb-22	1-Mar-22	1-Mar-22	25	97%	2,4	17
WOWI 6	4-Apr-22	7-Apr-22	7-Apr-22	47	94%	2,6	22
WOWI 7	21-May-22	19-Jun-22	19-Jun-22	186	76%	5,9	68
WOWI 8	13-Jun-22	25-Jun-22	25-Jun-22	141	60%	3,0	21
WOWI 9							

Table 6. Workover and Well intervention Result

- There are 3 candidates for drilling new wells in the oldest area of North Mahakam Sangasanga due to an increase in the estimated reserves in the layers affected by the low salinity injection.
- Implementing the low salinity injection program in the North Mahakam Sangasanga field has proved that implementing water injection in a reservoir with a lenses geometry and a limited conversion area can also produce good results in the production gain and revenue for the company. The implementation of low salinity injection can be continued in 6 layers in the NKL area.

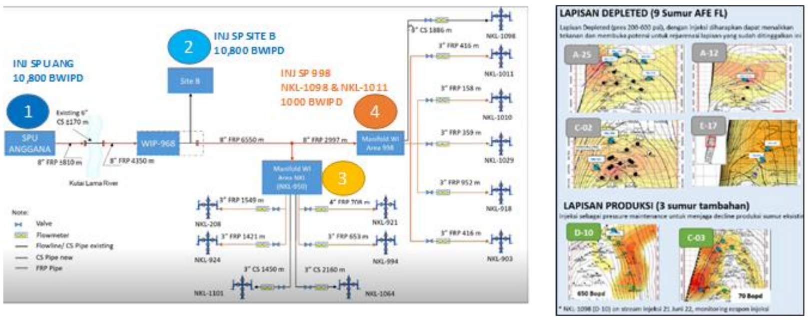

Figure 5. Future Low Salinity Injection Program in NKL Area

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