Downhole Water Drain from Gas Reservoir for Water Dumpflood in Oil Reservoir to Increase Hydrocarbon Production

Htet Myet Zin Naing and Suwat Athichanagorn

***Abstract*—**High water production and low gas recovery can be found in water-drive gas reservoirs because of water coning. To ameliorate this problem, "Downhole Water Drain" method can be applied to drain water from aquifer underneath the gas reservoir to another zone. If there is an oil reservoir underneath, "Water Dumpflood" can be performed simultaneously by dumping water into the oil reservoir to increase oil recovery at almost no cost. With these concepts, this study investigated a technique called "Downhole Water Drain for Water Dumpflood" (DWDDF) in comparison with the conventional bottom-up production via reservoir simulation based on rock and fluid properties commonly found in Thailand. Various operational parameters for both methods were examined in details in order to maximize hydrocarbon production. Simulation results demonstrate that the best case of DWDDF produce 16.47% more barrels of oil equivalent and 94.04% less unwanted water when compared with the conventional production technique.

***Keywords*—**Downhole Water Drain, Water Coning, Water Dumpflood, Water Production.

I. Introduction

In bottom-water drive gas reservoirs, water coning at the vicinity of the wellbore can occur because of differential pressure due to gas production. As a result, excessive water production can be seen at surface, and gas production is terminated by loaded water inside the well. Water production not only reduces the gas recovery but also incurs higher operating expenses on water treatment and disposal. Unwanted water production can be lowered by reducing the strength of the underlying water layer to control the water cone.

Various studies have been conducted by researchers to solve the gas well liquid loading problem. Arcaro and Basssiouni [1] discussed the co-production process for the Eugene Island field. This method improves gas recovery by producing water at high rates from wells located in the watered-out area (downdip area of the reservoir) to reduce the strength of the aquifer in order to maintain production from gas wells in the updip area. The authors concluded that the co-production technique can increase gas recovery by 21%. However, the limitation of co-production is a considerable amount of produced water has to be treated and disposed at surface.

Kamonkhantikul [2] conducted a study to investigate suitable operating conditions to apply the downhole water drain (DWD) method in a multi-layered system consisting of a bottom water-drive gas reservoir (upper gas reservoir) and partially depleted gas reservoir (lower gas reservoir) located at a deeper location. In this method, additional completion is created in the water zone to drain water to the lower gas reservoir to reduce the aquifer strength to mitigate water coning. At the same time, DWD can repressurize the lower gas reservoir to bring gas production again. The author concluded that DWD can improve gas recovery up to 16% from commingled and 13% from bottom-up production meanwhile it can considerably reduce water production.

Buranatavonsom [3] introduced a method called Downhole Water Dump Flood (DWDF) to solve the problem of water coning in a strong bottom-water drive gas reservoir. The author conducted a comparative study between conventional production method and DWDF by varying the perforation interval of the well in the gas reservoir. In this method, water from the aquifer underneath the gas reservoir is drained to the oil reservoir located underneath. The author reported that DWDF can also increase 21% of oil recovery over the conventional technique.

In this paper, the concept of "Downhole Water Drain for Water Dumpflood" (DWDDF) is examined to improve hydrocarbon production and at the same time reduce the amount of produced water. The objective of this study is to investigate the performance of the DWDDF technique with different operating conditions in comparison with the conventional bottom-up production technique.

II. The Concept of Downhole Water Drain for Water Dumpflood Technology

Downhole Water Drain for Water Dumpflood is the integrated concept of Downhole Water Drain and Water Dumpflood. A reservoir system suitable for this method must consist of a bottom water-drive gas reservoir at a shallower location and oil reservoir at a deeper location. To apply this method, there must be (1) water dumping well(s) which can produce gas from the upper reservoir and dump water into the lower reservoir at the same time to reduce water coning in the upper gas reservoir and flood the lower oil reservoir and (2) production well(s) which produces oil from the lower reservoir.

Manuscript received February 14, 2022. This work was supported in part by Chevron Thailand Exploration and Production.

Htet Myet Zin Naing is with the Department of Mining and Petroleum Engineering, Chulalongkorn University, Bangkok, Thailand 10330.

Suwat Athichanagorn is with the Department of Mining and Petroleum Engineering, Chulalongkorn University, Bangkok, Thailand 10330.

https://doi.org/10.17758/EARES11.EAP0422202

The dumping well is perforated in all three columns (gas, water, and oil). Gas and water completions are isolated by installing a packer inside the casing to produce gas and dump water separately. The production well is perforated only in the oil column. Fig. 1 illustrates the completions of these wells.

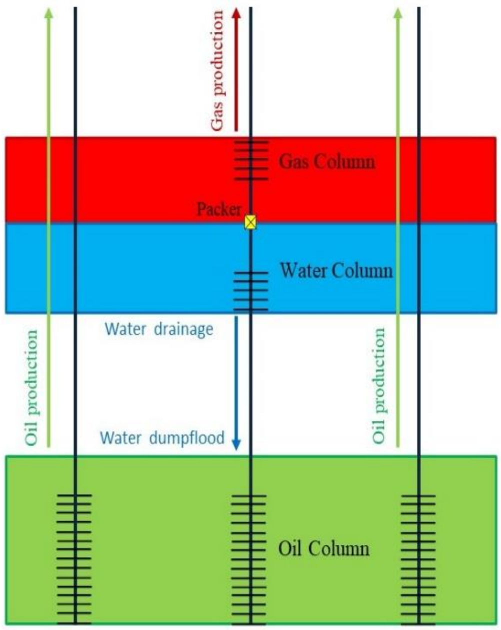

Fig. 1. Downhole water drain for water dumpflood configuration.

III. Research Methodology

Reservoir simulation was conducted in order to study the performance of the proposed method as well as the conventional bottom-up method. In this section, reservoir description and simulation study design are explained in details.

A. Reservoir Description

The reservoir model was constructed as a rectangular shape using Cartesian coordinates with rock and fluid properties commonly found in the Gulf of Thailand. This conceptual model consists of two homogeneous consolidated sandstone reservoirs having the same porosity of 0.2. The upper bottom water-drive gas reservoir and lower oil reservoir are separated by a shale layer. The top depths of the bottom water-drive gas reservoir and oil reservoir are 6,000 ft and 8,000 ft, respectively. The upper zone consists of 15 feet of gas column and 15 feet of water; the shale layer separating the upper and lower zone is 1,970 feet thick, and the lower oil reservoir is 100 feet thick. The length and width of both reservoirs are 3,150 feet and 750 feet, respectively. The reservoir model was created with 63x15x41 grid cells in the direction of x, y, and z, respectively. The grid arrangement of each zone in the z-direction is 10 grids for the gas zone, 20 grids for the water zone, 1 grid for shale layer, and 10 grids for the oil zone. The rock and fluid properties of each reservoir are shown in Table I.

TABLE I: Rock & Fluid Properties of Reservoir Model

Property	Bottom water-drive gas reservoir		Oil Reservoir
	Gas Zone	Aquifer	
Horizontal Permeability (mD)	15	15	100
Vertical Permeability (mD)	1.5	1.5	10
Initial water saturation	0.35	1	0.35
Initial gas saturation	0.65	0	0
Initial oil saturation	0	0	0.65
Gas gravity	0.6	-	0.85
Solution gas oil ratio (scf/stb)	-	-	200
Bubble point pressure (psia)	-	-	960.21
Reservoir pressure (psia)	2598		3464
Reservoir temperature (°F)	180		200
Rock compressibility (psi^{-1})	1.53×10^{-6}		

B. Simulation Study Design of Bottom-up and DWDDF

There are two production scenarios in this study: conventional bottom-up production and DWDDF. Three vertical wells are drilled through the gas and oil columns. For bottom-up scenario, all three wells are used to produce fluids from the lower oil reservoir until depletion first and then separately from the upper gas reservoir. For DWDDF, the three wells are used to produce fluids from the lower oil reservoir for a short period of time; then, the middle well is perforated in the gas column to produce gas, the water column to drain water, and the oil column to dump the water into the lower oil reservoir at the same time while the other two wells continue to produce fluids from the lower oil reservoir only as schematically illustrated in Fig. 1. The production constraints of all three wells for both production scenarios are tabulated in Table II. The simulation is stopped once the production condition reaches one of these controlled values.

TABLE II: Production Constraints

Production Constraint	Oil Production	Gas Production
Minimum Bottomhole Pressure (psia)	500	-
Minimum Tubing Head Pressure (psia)	-	300
Economic limit (stb/day or Mscf/day)	50	500
Maximum Water Cut (%)	90	-

IV. Results and Discussion

A. Bottom-up

To find out the best operating condition for the bottom-up production, well locations and perforation intervals of oil and gas columns were investigated. Fig. 2 shows the well locations investigated in this study. The dark blue location indicates the middle well location which was fixed while the other well locations were varied to red location (I-1=6, I-2=58), yellow location (I-1=11, I-2=53), and green location (I-1=16, I-2=48). All well locations in the J direction are fixed at the 8th grid (J=8). The oil perforation interval of all three wells was varied as 80%, 60%, and 40% from the bottom of the reservoir while the gas perforation interval of all three wells was varied as 80%, 60%, and 40% from the top.

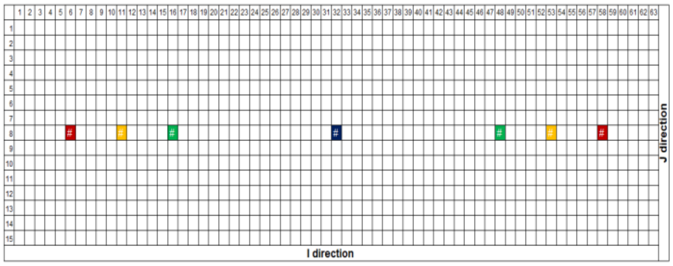

Fig. 2. Varied set of well locations.

TABLE III: Results for Bottom-up Production for Different Well Locations and Perforation Intervals for Oil Zone

Well location	Oil Perforation Interval	Oil Recovery	Water Production
	(%)	(%)	(STB)
I-1=6 & I-2=58	80	14.94	1,456
	60	15.68	1,522
	40	17.33	1,699
I-1=11 & I-2=53	80	15.04	1,456
	60	15.77	1,522
	40	17.58	1,719
I-1=16 & I-2=48	80	14.95	1,456
	60	15.75	1,529
	40	17.42	1,708

TABLE IV: Results for Bottom-up Production for Different Perforation Intervals for Gas Zone

Gas Perforation Interval	Gas Recovery	Water Production
(%)	(%)	(STB)
80	67.54	34,973
60	65.79	30,795
40	63.28	26,455

TABLE V: Results for Bottom-up Production for Different Perforation Intervals for Both Oil and Gas Zones

Perforation Interval		Total barrel of oil equivalent	Total Water Production
Oil	Gas		
(%)	(%)	(BOE)	(STB)
80	80	838,136	36,429
	60	836,009	32,251
	40	832,974	27,911
60	80	872,361	36,495
	60	870,234	32,317
	40	867,199	27,977
40	80	957,645	36,692
	60	955,518	32,513
	40	952,484	28,174

Simulation results for oil production from the lower reservoir as summarized in Table III indicate that oil recovery almost does not vary with well location but slightly decreases with increasing perforation interval of the oil zone. Well location has very small impact in the results because the reservoir is homogeneous with moderate permeability. Long perforation interval has a slight negative impact on oil production because liberated gas which forms when pressure falls below the bubble point migrates to the upper part of the reservoir and flows into the upper perforations, impeding oil flow and reducing the drive energy of secondary gas cap.

Since the effect of well location on oil recovery is very small, its effect on gas recovery is even smaller due to high gas mobility. Hence, the best well locations at I-1=11, I-2=53 were selected for the next step to investigate the effect of gas perforation interval on gas recovery.

For the upper gas reservoir, longer gas perforation interval moderately increases gas recovery but strikingly increases water production as illustrated in Table IV. Longer gas perforation interval can increase gas production as it reduces pressure loss around the well as long as water coning does not cause liquid loading problem in the wells. Note that simulation runs of all gas production scenarios stopped due to the specified economic limit, not liquid loading.

In order to find the best production scenario, gas production was converted to barrel of oil equivalent (BOE) and combined with oil production to determine total BOE. Note that 6000.3 SCF of gas equals to 1 BOE. Table V summarizes simulation results for total BOE and total water production from both reservoirs for bottom-up production scenario. Results reveal that the highest BOE of 957,645 barrels can be obtained from perforation intervals of 40% for the oil zone and 80% for the gas zone. However, this scenario produces the highest amount of water of 36,692 barrels since longer gas perforation interval can increase not only gas production but also water production.

B. DWDDF

To find out the best operating condition for DWDDF, several variables were investigated. The oil perforation interval of all three wells was varied as 80%, 60%, and 40% from the bottom while the gas perforation interval of the middle well was varied as 80%, 60%, and 40% from the top of the reservoir and the perforation interval of the water zone of the middle well was varied as 80%, 60%, and 40% from the bottom. The starting time for DWDDF was varied based on oil production phases: (1) at the first day of the oil production, (2) at the end of oil plateau rate, and (3) at the economic oil production rate. Note that locations of the three wells were chosen to be the same as the ones in the bottom-up scenario.

According to simulation results shown in Fig. 3 – 5, 40% perforation cases yield higher total BOE compared to 60% and 80% because of less free gas production, similar to the results of bottom-up production scenario. In general, cases with shorter gas perforation interval yield a little higher total BOE than longer ones because there is a higher amount of gas crossflowing from the gas reservoir to the lower oil reservoir which helps improve oil recovery. Longer water perforation interval cases induce more water to be dumped to the lower oil reservoir. Thus, more oil is displaced for production, resulting in higher total BOE. Regarding dumpflood, starting it at the economic oil rate yields the highest total BOE for 40% oil perforation cases (See Fig. 5) since a high amount of gas cross flows into the oil reservoir via the middle well due to lower pressure and facilitates oil flow inside the reservoir. Note that more gas is preferable in this case since free gas is not a problem for 40% perforation of the production well. On the contrary, gas reduces total BOE for 80% oil perforation cases as gas flows into the upper perforations of the oil reservoir. When compared among the three starting times, the end of plateau gives the highest total BOE due to the highest amount of water cross flowing into the lower oil reservoir as a result of long dumping time. Starting dumping water on the first day does not yield the highest amount of dumped water as the lower reservoir still has high pressure at the time. For 60% oil perforation, the best starting time swings between the economic rate and the end of plateau due to mixed impacts between the volumes of gas and water cross flowing into the lower reservoir.

In summary, the case yielding the highest total BOE (1,115,416 barrels) is 40% oil perforation, 80% water perforation, 40% gas perforation, and starting dumpflood at the economic rate. The 40% oil perforation helps reduce the amount of free gas in the reservoir and consequently increase oil production. The 80% water perforation allows more water to be dumped into the oil reservoir while the 40% gas perforation reduces the amount of water flowing up to the gas perforations. Starting dumpflood at the economic rate allows more gas to cross flows into the lower oil reservoir due to large pressure difference between the two reservoirs.

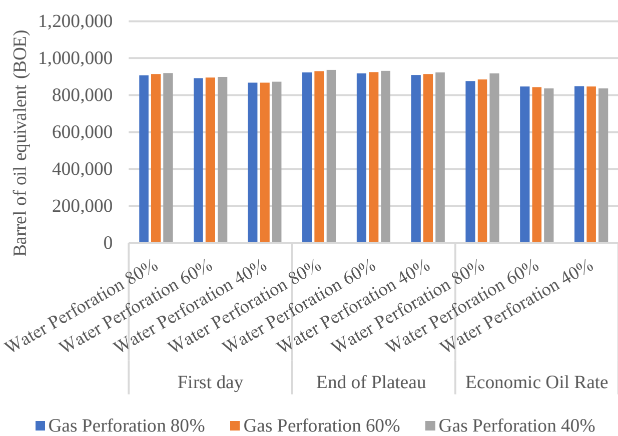

Fig. 3. Total BOE for DWDDF at 80% oil perforation interval for various gas and water perforation intervals as a function of different starting times for water dumpflood.

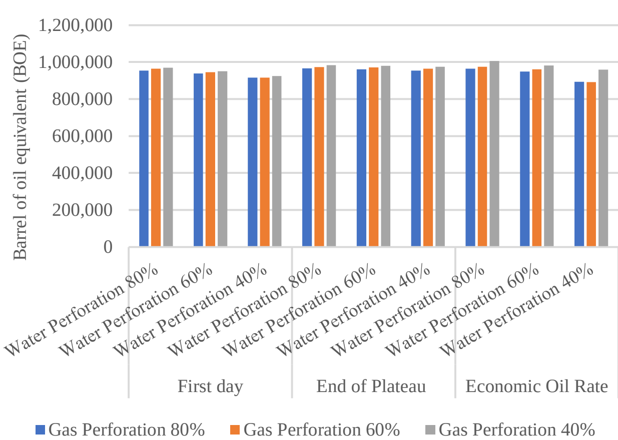

Fig. 4. Total BOE for DWDDF at 60% oil perforation interval for various gas and water perforation intervals as a function of different starting times for water dumpflood.

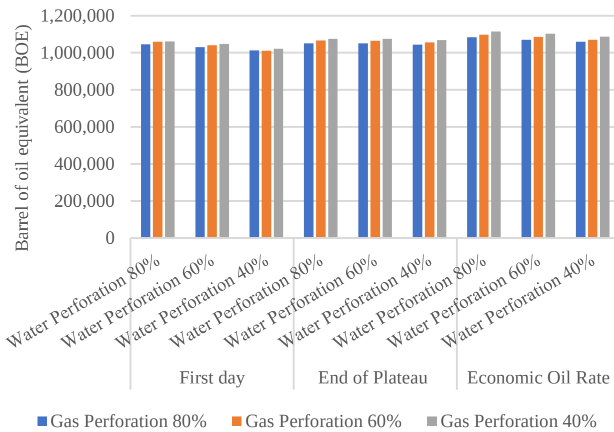

Fig. 5. Total BOE for DWDDF at 40% oil perforation interval for various gas and water perforation intervals as a function of different starting times for water dumpflood.

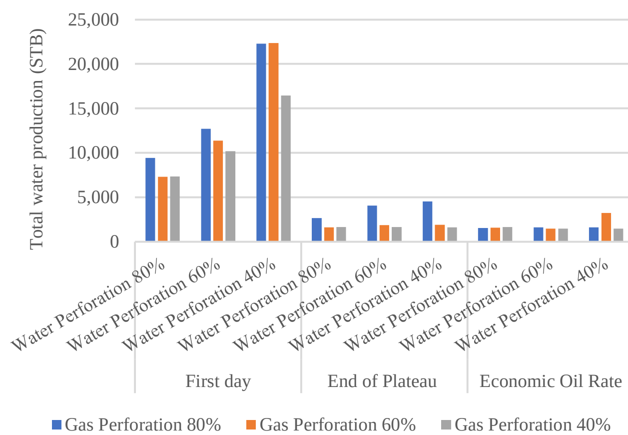

Fig. 6. Water production for DWDDF at 80% oil perforation interval for various gas and water perforation intervals as a function of different starting times for water dumpflood.

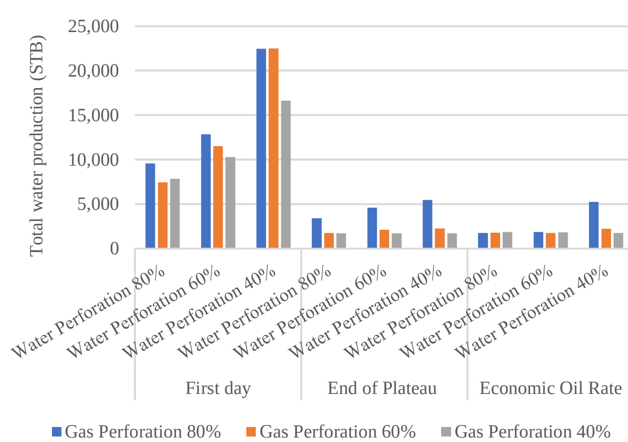

Fig. 7. Water production for DWDDF at 60% oil perforation interval for various gas and water perforation intervals as a function of different starting times for water dumpflood.

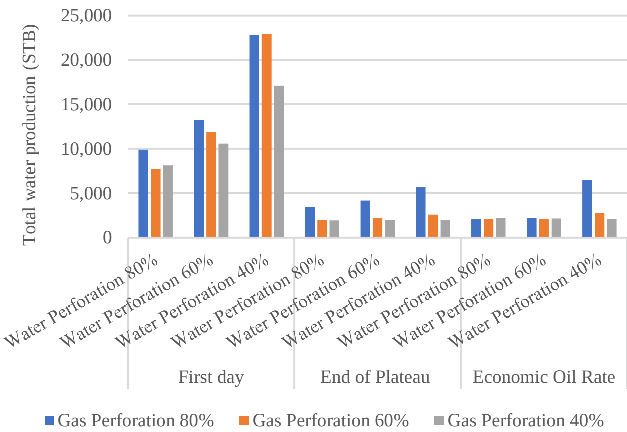

Fig. 8. Water production for DWDDF at 40% oil perforation interval for various gas and water perforation intervals as a function of different starting times for water dumpflood.

For unwanted water production, cases in which water dumplood is started on the first day of oil production show high water production compared to other starting times as illustrated in Fig. 6 - 8. As the lower oil reservoir still has high pressure at the beginning, the amount of water that can be dumped into the lower reservoir is small. Instead, a large amount of water flows to surface. For the case yielding the highest total BOE (40% oil perforation, 80% water perforation, 40% gas perforation, and starting dumpflood at the economic rate), the water production is only 2,188 barrels which is among low water production cases.

C. *Bottom-up vs. DWDDF – Comparison Results*

In this section, the performance of DWDDF and conventional bottom-up production techniques are compared using total BOE as a key criterion. According to the results shown in Fig. 9, every DWDDF case can perform better than bottom-up when they have the same oil and gas perforation intervals. Not only total BOE is increased but also unwanted water production is reduced when DWDDF technique is applied. Comparing between the best bottom-up scenario (40% oil perforation and 80% gas perforation) and the best DWDDF (40% oil perforation, 40% gas perforation, 80% water perforation and starting dumpflood at the economic rate), DWDDF can increase total BOE by 16.47% from 957,645 to 1,115,416 barrels and reduce water production by 94.04% from 36,692 to 2,188 barrels. This incremental production of total BOE and reduction in water production is achieved by gas and water crossflow from the upper gas reservoir to the lower oil reservoir. Gas crossflow induces lower gas production from the bottom water-drive gas reservoir; however, it helps improve oil production from the lower reservoir.

V. Conclusion

Gas reservoir associated with bottom-drive aquifer typically produces high volume of water which reduces gas recovery by liquid loading, and the operation cost increases due to produced water treatment and disposal process. The benefits of DWDDF technology investigated in this study are (1) less water production from the water-drive gas reservoir as water is dumped into the oil reservoir and (2) more oil recovery as a result of water dumpflood. For the same perforation intervals of gas and oil columns, hydrocarbon recovery in terms of barrels of oil equivalent obtained from DWDDF is always higher than the one from conventional bottom-up production.

For the reservoir characteristics and rock and fluid properties used in this study, the best condition for DWDDF is 40% oil perforation (short interval to impede free gas from flowing into the production well), 80% water perforation (long interval to induce more water as well as gas to be dumped into the lower oil reservoir), and 40% gas perforation (short interval to reduce water production at surface), and starting dumpflood at the economic rate (late starting time to allow more cross flow of water and gas to the lower reservoir as its pressure is depleted at late time). This best scenario produces 16.47% more total barrels of oil equivalent and 94.04% less water in comparison with the best scenario in conventional bottom-up technique. The proposed technique of DWDDF is highly beneficial as it not only brings more revenue from hydrocarbon production but also reduces the cost of water treatment and disposal.

APPENDIX

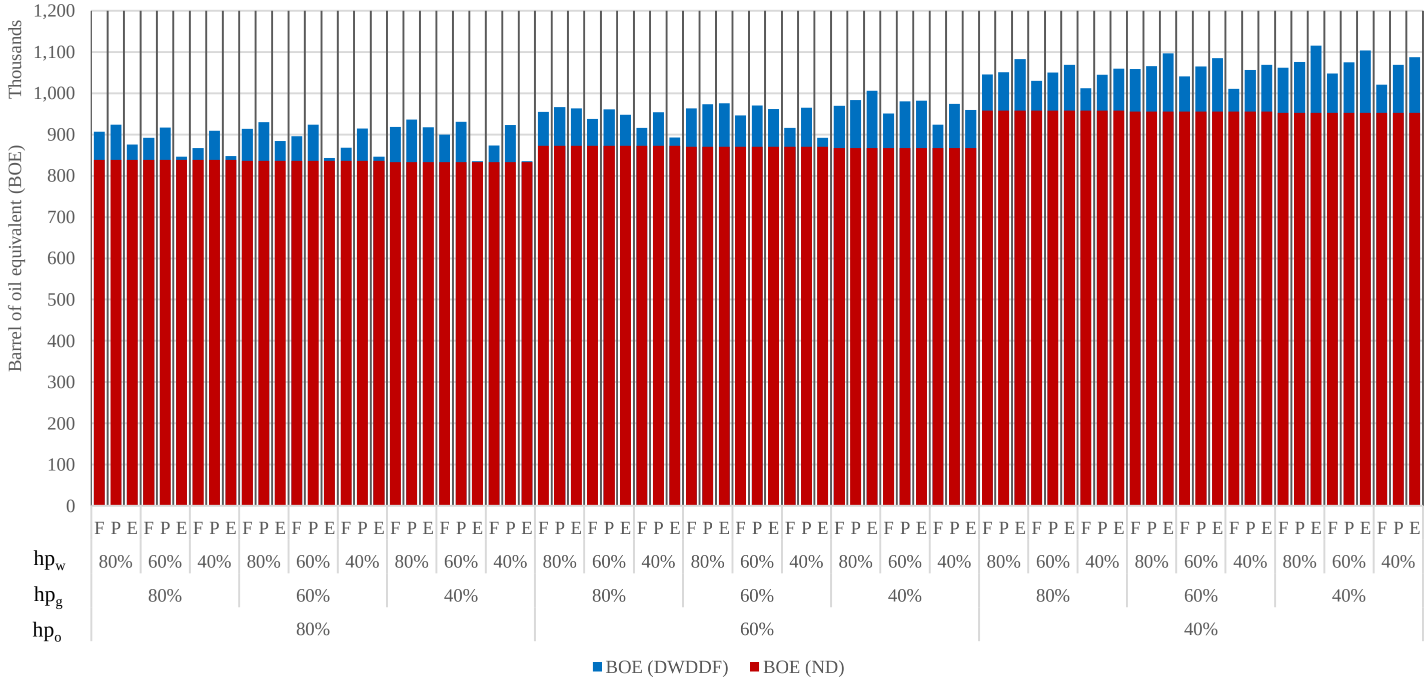

Fig. 9. Total BOE for Bottom-up production and DWDDF at various oil, gas, and water perforation intervals as a function of different starting times for water dumpflood (Note that hp_w, hp_g and hp_o represent perforation intervals of water, gas and oil, respectively whereas F, P, E stands for dumpflood starting time of first day, end of plateau and economic rate.

ACKNOWLEDGMENT

The authors would like to thank Chulalongkorn University for providing graduate scholarship for Htet Myet Zin Naing and Schlumberger Thailand for providing reservoir simulation software used in this study.

REFERENCES

[1] Arcaro, D. P., & Bassiouni, Z. A. (1987). The Technical and Economic Feasibility of Enhanced Gas Recovery in the Eugene Island Field by Use of the Coproduction Technique. Journal of petroleum technology, 39(05), 585-590. https://doi.org/10.2118/14361-PA

[2] W. Kamonkhantikul, "Downhole water drain from bottom water-drive gas reservoir into partially depleted gas reservoir", M.Eng. thesis, Dept. Mining and Petroleum Eng., Chulalongkorn Univ., Bangkok, Thailand, 2015.

[3] Buranatavonsom, N., "Water Coning Management in Gas Reservoir via Downhole Water Dump Flood," in SPE Annual Technical Conference and Exhibition, OnePetro, October 30, 2011. https://doi.org/10.2118/152369-STU

Htet Myet Zin Naing is currently a master's student, specializing in petroleum engineering at Chulalongkorn University. He was born in Yangon, Myanmar. He earned a B.E degree in petroleum in 2019 from Technological University (Thanlyin), Yangon, Myanmar.

He has been an SPE member since 2018, and he also served as president of Thanlyin Technological University SPE Student Chapter during the 2018 – 2019 academic term. His research interests include water coning management, water dumpflood, CO_2 EOR and sequestration with the emphasis on reduction not only implementation cost but also harm upon the environment.

Zin Naing received a graduate scholarship award from the Chulalongkorn University's Graduate Scholarship Program for ASEAN and Non-ASEAN Countries in 2020. He was also an exchange student at Chulalongkorn University in 2019 with the contribution of the Chulalongkorn University's One Semester Scholarship Award.

Suwat Athichanagorn is an assistant professor and head of petroleum engineering section at the Department of Mining and Petroleum Engineering, Chulalongkorn University, Thailand. He was an adjunct faculty member at Asian Institute of Technology and Sirindhorn International Institute of Technology. He was also instructor for Thailand Petroleum Training Institute and once served as an Editor in Charge for Geological and Geo-Resource Engineering for ASEAN Engineering Journal.