EOR in Indonesia: past, present, and future

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Abstract: This paper presents the history of the application of enhanced oil recovery (EOR) methods in Indonesia, its current status and its future. Various efforts to apply EOR methods have been carried out in the country either in laboratories, pilot projects, field trials, or full field scale operations during the last several decades. Indonesia was one of the very few countries who have experience in steamflooding operation. In terms of production, Duri Field where the steamflood has been applied for more than 30 years is still the largest steamflooding project in the world. The project has triggered other EOR methods such as gas injection, chemical injection, microbial injection, seismic vibration and electrical methods to develop for various mature fields. Currently, steamflooding is still the leading EOR method applied in Indonesia while chemical and gas injection are emerging as potential methods to improve oil recovery in the near future. Other methods such as microbial injection, seismic vibration, and electrical methods are still under research and field trial before their full implementation in the future. [Received: September 22, 2015; Accepted: May 15, 2016]

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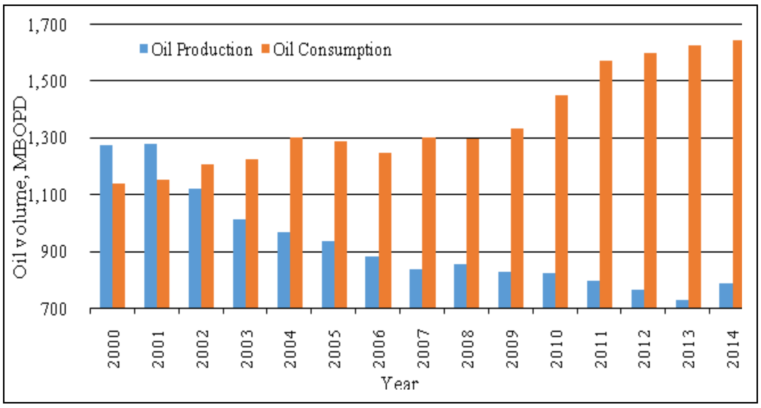
1 Introduction

As the largest archipelago in the world, Indonesia economy is developing very rapidly and various energy sources are required to fulfil its demand. At present, fossil fuel is still the number one source of energy. It contributes 29.2% to the total energy sources (MEMRRI, 2014a). On the other hand, the oil production has been declining consistently since 1995 with 4.3% of decline rate estimated in 2014 (SKK Migas, 2014). According to SKK Migas's (2014), the national oil production average at the time was 789,000 BOPD. Figure 1 shows the increasing oil consumption and the decreasing oil production during the period of 2000 to 2014 (MEMRRI, 2015). Furthermore, the national oil reserve has also been depleting since 2000 as shown in Figure 2. The oil production is about 300 million barrels per year and there were no significant additions to the reserve since that time causing the reserve to run out within less than 15 years. Thus, the Indonesian oil industry has problems, one being that the reserve replacement ratio (RRR) is quite low as it is only approximately 44% in 2013 as shown in Figure 3. This means that the ratio of reserve discovery to oil production is less than 1. To meet its oil consumption, Indonesia has been importing crude oil since 2000 (Figure 4). As there is no major reserve addition, it is essential for the nation to increase the oil production by optimising its mature fields through the implementation of EOR methods. Currently, the most extensive application of EOR methods is steamflooding. The method has been successfully implemented field wide in Duri Field for improving its heavy-oil recovery since 1985. In terms of production, this project is the largest steamflooding activity in the world known as Duri Steamflood or DSF (Pearce and Megginson, 1991; Koottungal, 2014). The contribution of DSF to the total national production is about 20% (SKK Migas, 2011). In the meantime, the oil production from most other fields has been declining and some have achieved their peak production during primary recovery or secondary recovery stages (Aprilian et al., 2003a, 2003b). Majority of the fields are having high water cut of over 80% and in some fields are even almost 99%. About 94% of the fields are getting mature and only 6% of them are considered as green fields regardless the huge original oil in-place. It is strongly believed that abundance of oil still remains in the reservoirs where the total remaining oil in-place is estimated as 49.5 billion barrels (SKK Migas, 2011).

The common way to increase oil production quickly is by drilling new or infill wells. However, drilling costs are considerably expensive and tend to increase every year not to mention the difficulty in finding new drilling spot in mature fields. The cost for drilling new wells was averaged as a million dollars per well in 2014. Despite the high success rate for exploration well, which was about 74% in 2013 as mentioned, the ratio of discovery to production has been quite low. The chance to increase production then comes from EOR applications. In fact, after the primary recovery stage, the oil recovery process is traditionally continued to secondary recovery and/or enhanced oil recovery (EOR) stages.

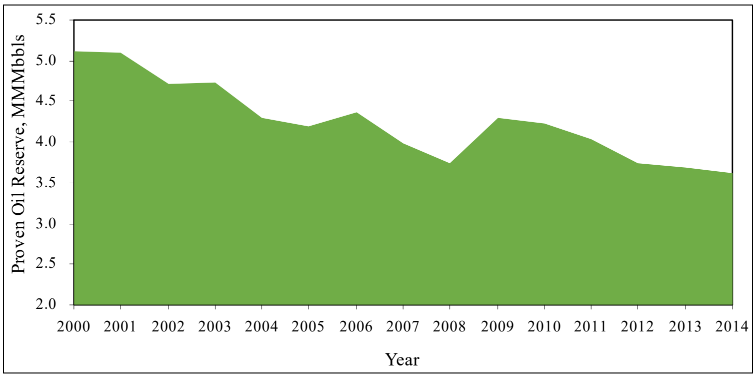
This paper presents the application of EOR methods in Indonesia and its current status as well as its future. In some fields, the methods have been established and proved to prolong successfully the fields' life. In some other fields, they have been or just started to conduct laboratory and simulation studies, field trial, or pilot projects. The works have provided invaluable data and much important information. They could be used as lesson learned and guidelines for deciding the EOR methods to be implemented in the future.

Figure 1 Oil production and consumption (see online version for colours)



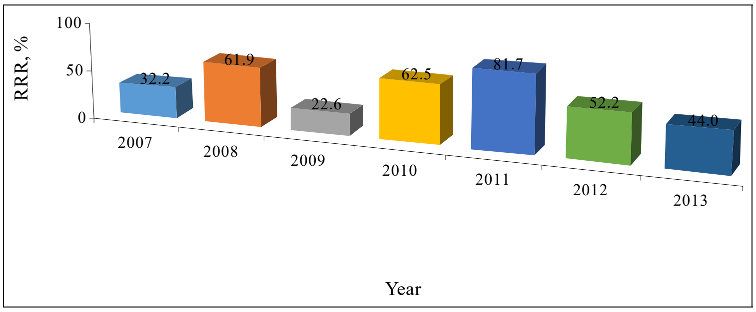
Source: MEMRRI (2015)

Figure 2 Proven oil reserve (see online version for colours)



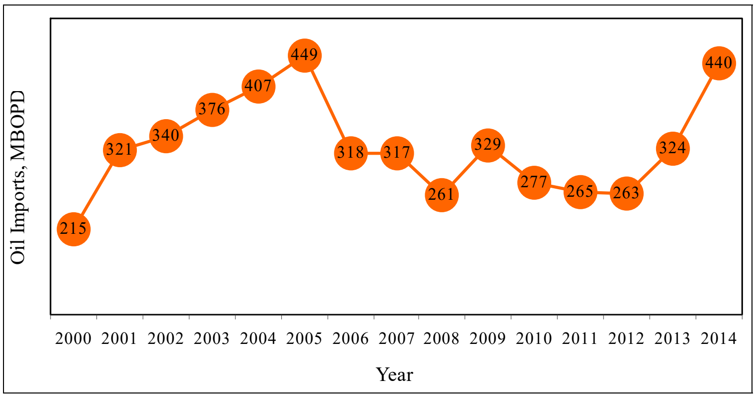
Source: SKK Migas (2014)

Figure 3 Reserve-to-replacement ratios (see online version for colours)



Source: SKK Migas (2013)

Figure 4 Oil imports (see online version for colours)



Source: MEMRRI (2015)

2 Past and current activities and performances

2.1 Past and current projects

2.1.1 Steamflooding at Duri and Minas Fields

Thermal recovery methods have been applied in Indonesia since 1967. The first thermal recovery project applied a huff-and-puff technique. The approach was the beginning of steamflooding project that have been able to prolong Duri Field production until present days. Since 1975, Duri Field had been implementing two pilots of EOR methods. These were caustic injection and steamflooding. The reservoir target was between 140 ft to 240 ft and the oil is categorised as heavy oil with 22 °API gravity. While the steamflooding project succeeded the field recovery improvement, the caustic injection was discontinued due to its failure in 1979. Thereafter, steamflooding was chosen to be fully implemented in Duri Field and it has been since the largest EOR project in the country and is currently still the largest steamflooding operation in the world (Pearce and Megginson, 1991; Sutadiwiria and Azwar, 2011; Koottungal, 2014). The project has been expanded in April 1985 for Area 1. Afterwards, the expansion was continued to Area 2 in 1986 and so until it reached Area 14 in 2010. The peak production of approximately 300,000 BOPD was achieved in 1994. Regardless the current production rate and the expansion that includes North Duri Development (NDD) project, the total production of Duri Field had once declined to the lowest level of only 165,057 BOPD (SKK Migas, 2012, 2013). So far, steamflooding has been implemented only in Duri Field since the field is considered to have the most suitable reservoir condition owing to the properties of heavy oil, shallow reservoir depth and good reservoir thickness in a wide area.

Following the successful steamflooding implementation in Duri Field, the neighbouring Minas Field has been attempted for similar method since 1998. The field has light oil that the project was called Minas light oil steamflood (Minas LOSF). Regardless the oil gravity, an analysis of EOR screening criteria has in fact shown that steamflooding was one of the most favourable EOR methods for the field. Unfortunately, the field trial was unsuccessful due to some technical reasons. A subsequent study concluded that there were at least two reasons why the field trial failed: one was the uncompleted geologic attributes characterisation and the other was the unexpected rock-steam interaction (Ehrlich et al., 1997). Another study explained that the failure was because of severe steam channelling through thief zones (Dehghani and Ehrlich, 2001). As a result, steamflooding has never been fully implemented in Minas Field. Table 1 shows the thermal recovery activities that have been operated in Duri and Minas Fields involving field trials and full-field scale projects since 1967.

Table 1 Thermal recovery activities

No.	*Field name*	*Status*	*EOR type*	*Year*	*EOR production*	*Remarks*	*References*
1	Duri	Field trial	Huff and puff	1967	No information	Shifted to steamflood	SPE 21527
2	Duri	Field trial	Steamflood	1975	No information	Successful	SPE 21527
3	Duri	Full project	Steamflood	1985	190,000 BOPD in 2014	Successful	SPE 2152 and Koottungal (2014)
4	North Duri Dev. (NDD)	Full project	Steamflood	2010	43,875 BOPD in 2012	Successful	SKK Migas (2012)
5	Minas	Field trial	Steamflood	1998	-	Failed to improve recovery	SPE 37541

Table 2 Gas injection activities

No.	*Field name*	*Status*	*EOR type*	*Year*	*EOR production*	*Remarks*	*References*
1	Handil (phase I)	Full project	Lean gas injection	1995–1999	1,600 MBO (cumulative)	Successful	SPE 57289, Widjayanto et al. (2001), SPE 144914, Santoso and Tjiptowiyono (1997)
2	Handil (phase II)	Full project	Lean gas injection	2000	1,200 MBO (cumulative)	Successful	SPE 57289, Widjayanto et al. (2001), SPE 144914, Santoso and Tjiptowiyono (1997)
3	Jatibarang	Under study	CO_2 injection	2012	-	Laboratory and simulation	SKK Migas (2012), SPE 97507 and Paryoto et al. (2006)
4	Gemah	Under study	CO_2 injection	2012	-	Laboratory and simulation	SKK Migas, (2012), SPE 97507

2.1.2 Gas injection at Handil Field

Gas injection studies have been carried out since 1980s to evaluate the injection capability in enhancing oil recovery in Indonesia. Among the conducted field tests, lean hydrocarbon gas injection was implemented in waterflooding operations through an immiscible displacement mechanism. However, the project was discontinued early for economic reasons. One of the very first fields to implement gas injection successfully was Handil Field. Commencing in 1995, the first three years of the operation yielded additional oil production of about 1.6 million barrels (Gunawan and Caie, 1999). In 2000, after the second phase of the injection was initiated, the operation yielded additional oil production of about 1.2 million barrels in only 1.5 years (Widjayanto et al., 2001). Gas injection activities either studies or full field projects are shown in Table 2.

2.1.3 Chemical injection at Handil Field and some other fields

Chemical injection was initiated at Handil Field in 1980 using alkaline-surfactant-polymer (ASP). The project had been unfortunately suspended for a few years afterwards due to technical reasons and low oil prices (Hadiaman et al., 2011). Nowadays, some notable progress in chemical flooding field trials and pilot projects have been reported such as those implemented in Minas, Kaji, Semoga, Meruap, Tanjung, Handil, Widuri, Zamrud, Pedada, and Limau Fields (SKK Migas, 2014; Bou-Mikael et al., 2000; Rilian et al., 2010; Zulfikar et al., 2014; Wibowo et al., 2007; Nugroho and Ardianto, 2010). These projects mainly used surfactant and polymer as the chemical substances. In Meruap and Limau Fields, a huff-and-puff injection technique was applied. The trials and pilots have provided some insights and evidences of the capability of chemical EOR to increase oil production regardless unsuccessful projects in some fields. The utilisation of local materials for the surfactant and polymer has also been studied to reduce the related costs. Some chemicals were derived from several domestic sources such as palm fruits, palm bunches, and pulp industries (Suryo and Murachman, 2001). Table 3 shows chemical injection activities including research works, field trials, and pilot projects since 1975.

2.2 Past and current researches

2.2.1 Gas injection studies

The gas injection project developed and implemented at Handil Field has been studied under experimental and simulation methods in 1997 (Santoso and Tjiptowiyono, 1997). Gas injection programs conducted in the laboratory and through simulation have also been done for Jatibarang Field located in West Java Province and Gemah Field located in Jambi Province (SKK Migas, 2012, 2013; Suarsana et al., 2005). Simultaneous injection of CO_2 and surfactant has been examined under experimental work by Lemigas and Bandung Institute of Technology (Brioletty et al., 2005). Using oil samples taken from an oil field in the Natuna Sea, an experimental work by Abdassah et al. (2000) indicated that CO_2 injection has potential in improving oil recovery. Utilisation of flared gas from Bontang LNG Plant, Ammonia Plant, and LNG Flue Gas Plan in Kalimantan Island was studied for improving oil recovery at fields in the area (Tobing and Sugihardjo, 2005). In some other fields, excessed flared gas has also been used for injection to maintain reservoir pressure such as that in Kaji and Semoga Fields located in South Sumatra

(Janitra et al., 2012). Based on results of these studies, many investigators suggested that gas injection has very much high potential to increase oil recovery. In this regards, South and Central Sumatra Basins are among the most promising EOR targets for gas injection applications. According to a study conducted by a government research institute named the Research and Development Center for Oil and Gas Technology or Lemigas, approximately 58% of Indonesian EOR targets are located in the two basins. Also, it has been found that 64 out of 136 candidate reservoirs for CO_2 injection are in fact located in South Sumatra Basin (Lemigas, 2004).

Table 3 Chemical injection activities

No.	*Field name*	*Status*	*EOR type*	*Year*	*EOR production*	*Remarks*	*References*
1	Duri	Field trial	Caustic injection	1975	-	Failed to improve oil recovery	SPE 21527
2	Handil	Field trial	ASP	1980	N/A	Not economic at that time	SPE 144914
3	Minas	Pilot project	Surfactant	2013	670 BOPD for 1 well	Successful	SKK Migas (2013), SPE 64288
4	Kaji and Semoga	Field trial	Surfactant huff and puff	2013	140 BOPD from 12 wells	Predicted	SKK Migas (2013), SPE 130060
	Kaji and Semoga	Pilot project	Surfactant polymer	2014	10,966 barrel	Successful	SKK Migas (2014)
5	Meruap	Field trial	Surfactant huff and puff	2012	59%–93% oil increment from 2 wells	Successful	Zulfikar et al. (2014) and Kristanto and Bintarto (2008)
6	Tanjung	Field trial	ASP	2013	225 BOPD from 4 wells	Successful	SKK Migas (2013)
	Tanjung	Pilot project	Surfactant	2014	18 MSTB of 169 MSTB	Failed	SKK Migas (2014)
7	Handil	Under study	Surfactant	2012	-	Laboratory work	SKK Migas (2012)
8	Widuri	Field trial	Surfactant	2013	2,500 BOPD from 1 well	Predicted	SKK Migas (2013), SPE 64288, SPE 130060, Zulfikar et al. (2014) and Wibowo et al. (2007)
9	Zamrud	Field trial	Surfactant huff and puff	2013	No information	No report	SKK Migas (2012)

Table 3 Chemical injection activities (continued)

No.	*Field name*	*Status*	*EOR type*	*Year*	*EOR production*	*Remarks*	*References*
10	Pedada	Field trial	Surfactant huff and puff	2013	No information	No report	SKK Migas (2012)
11	Limau	Under study	ASP	2007	-	Laboratory and simulation works	SKK Migas (2012), SPE 127728 and Wibowo et al. (2007)
	Limau	Pilot project		2010	3,100 BOPD	Successful	SPE 127728
12	Kenali Asam	Field trial	No information	2012	No information	Failed	SKK Migas (2013)
13	Ledok	Field trial	No information	2012	No information	Failed	SKK Migas (2013)

2.2.2 Chemical injection studies

Various chemical injection studies have been carried out since 2001. Gajah Mada University has long been developing EOR chemicals such as surfactant and co-surfactant through experimental and simulation works (Suryo and Murachman, 2001). Chemical injection using surfactant in Jatibarang Field was also studied through an experimental work (Paryoto et al., 2006). Lemigas conducted various and extensive chemical screening studies using surfactant and polymer including efforts of experimental works for reactivating mature fields with high water cuts (Eni et al., 2007, 2008; Tobing, 2012). An alternative way of chemical injection by surfactant soaking has also been examined. The methodology was investigated in the laboratory using oil and core samples taken from the real field (Kristanto and Bintarto, 2008). An extensive polymer injection study was carried-out specifically for South Sumatra Basin in which most of the oil fields has been mature. In spite of the field maturity, the oil remaining in the reservoirs is still more than 70% of the original oil in-place. According to the screening criteria used in the study, polymer injection is a favourable method to improve oil recovery for the reservoirs (Lemigas, 2004). One of important conclusions of the study showed that approximately 20 out of 23 fields can properly be selected as candidates for chemical injection.

2.2.3 Microbial EOR studies

Another EOR method that has long been considered to apply in Indonesian oil fields is the one based on bacterial activities. The method is traditionally known as the microbial enhanced oil recovery or simply MEOR (Bae et al., 1996) and was introduced publicly in 1984 (Gregory, 1984). This method has been since extensively studied and developed in some countries including Indonesia. Despite the promising result of studies in laboratory, the method has not been implemented as a full field scale project (Dietrich et al., 1996). According to the study by Maudgalya et al. (2007), this method has not been widely implemented not only because of technical but also economic reasons.

In Indonesia, several microbial EOR studies have been conducted since 1999. One of the very first studies involved sample fluids such as formation water, oil, and soil taken from various oil fields. These include, for example, oil fields located in Cepu, Cirebon, Rantau, Prabumulih, and Jambi Districts to cover wide variety of cases in the experimental works (Kadarwati et al., 1999). Lemigas, together with an oil company, subsequently examined a microbial EOR experimental study for various fields located in Central Sumatra Basin including Balam South, Bangko and Minas (Kadarwati et al., 2001). Taking fluid samples from the corresponding fields, the study suggested that the method offers a very good opportunity for improving oil recovery. Another study to examine the ability of the microbes to improve oil recovery was conducted using oil and water samples taken from oil fields located in West Java Province (Halim et al., 2008). Some microbial EOR studies and activities in Indonesia are shown in Table 4.

Table 4 Microbial injection activities

No.	*Field name*	*Status*	*EOR type*	*Year*	*EOR production*	*Remarks*	*References*
1	Balam South	Under study	Microbial	2001	-	Laboratory work	SPE 57316, SPE 72126, Halim et al. (2008)
2	Bangko	Under study	Microbial	2001	-	Laboratory work	SPE 57316, SPE 72126, Halim et al. (2008)
3	Minas	Under study	Microbial	2001	-	Laboratory work	SPE 57316, SPE 72126, Halim et al. (2008)

2.2.4 Seismic vibration and electrical EOR studies

Seismic vibration is one of the EOR methods that may be applied if suitable field conditions are met. This method has been studied at Bandung Institute of Technology through laboratory experiments in order to find out the effects of vibration on fluid and rock properties that may change the recovery (Ariadji, 2005). The results showed that porosity, absolute permeability, and end points of oil and water relative permeabilities were increased. On the other hand, residual oil saturation and irreducible water saturation were decreased. Seismic vibration method has also been experimented in a field scale. The trial was conducted at Kampung Minyak located in South Sumatra Province. The result showed that the method provided incremental oil production of about 10% of the existing production (Kurnely et al., 2006).

The electrical EOR method was once investigated in a field scale. The trial was conducted at Old Rimau Field (SKK Migas, 2014). This activity is currently in progress and yet no published report found in the literature by the time this paper is written. Table 5 shows the seismic vibration and electrical EOR field trial activities.

Table 5 Seismic vibration and electrical EOR activities

No.	*Field name*	*Status*	*EOR type*	*Year*	*EOR production*	*Remarks*	*References*
1	Kampung Minyak	Field trial	Seismic vibration	2006	10% increment of oil production	Successful	SPE 93112, SPE 101242
2	Old Rimau	Field trial	Electrical	2014	-	In progress	SKK Migas (2014)

3 Prospects and barriers

3.1 Prospects

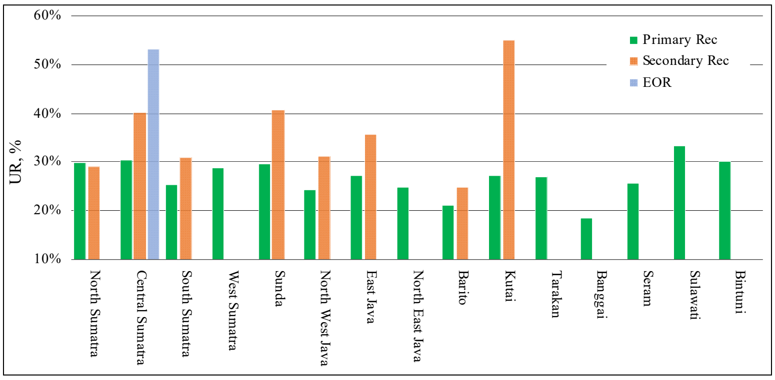
3.1.1 Huge remaining oil in-place

Indonesia oil production has been declining rapidly since the historical second peak production achieved in 1995. Until present days, the primary and secondary production stages have been dominant leaving a large amount of oil to remain in the reservoirs. Figure 5 shows the ultimate recovery factors for 15 major exploited basins in Indonesia. The figure shows that most oil fields in the basins have been exploited under primary and secondary stages with the recovery factors averaged at 30%. The one and only basin that has been implementing EOR method extensively is Central Sumatra Basin and the one and only oil field in the basin is Duri Field. Another field in the basin named Minas has been applying waterflooding extensively for decades. The project has been the largest waterflooding project in the nation. According to SKK Migas (2011), the remaining oil nationwide is estimated at about 49.5 billion barrels while according to Lake (1989), rough estimates of additional oil recovery by EOR methods are 5% to 15% for chemical methods, 10% to 65% for steamfloods, and 5% to 15% for gas injections. Therefore, assuming EOR methods are able to convert at least 5% to 10% of the existing resources; their implementation may lead to an additional oil recovery of 2.48 to 4.95 billion barrels.

3.1.2 Oil fields under primary and secondary recovery stages

While the national oil production has been declining, majority of fields had turned to be mature. In spite of low production rate, a large number of fields are currently producing with primary and secondary recovery stages leaving behind much information for selecting the most appropriate EOR method (Kurnely et al., 2006). For example, waterflooding operations may provide valuable information on reservoir connectivity between injectors and producers. Such information is an essential key for developing suitable EOR methods in the future. From the EOR application point of view; for example chemical or gas injection application, it is necessary to know the path where the displacing and the displaced fluids will be flowing. The EOR application is the best way to sweep out the residual oil after primary and secondary recovery stages in order to increase the recovery.

Figure 5 Ultimate recoveries (see online version for colours)



Source: SKK Migas (2014)

3.1.3 Government support for EOR project

Income from the oil industry affects strongly Indonesian national budget every year. The income excluding that from the natural gas was estimated at about $15.68 billion in 2014 (SKK Migas, 2014). In order to increase the oil production which in turn increases the government income, the Indonesian Government published the Presidential Decree No. 2 in 2012. The decree is aimed to promoting oil production to at least 1.0 million barrels per day beyond 2012. By publishing the decree, the Indonesian Government encouraged operating oil companies to apply EOR technologies in order to increase oil production as targeted. At the same time, the operating oil companies have been provided a political support and guideline from the government to develop related activities for implementing EOR in the near future.

3.1.4 Experience in EOR applications

Indonesia has been experiencing a huge-scaled steamflooding project in Duri Field since 1985. It is still operating today and even still expanding to some neighbouring areas. This project has been a benchmark for the government and operating companies in applying EOR. The steamflooding has been proved as an EOR method in improving oil production; in this case, heavy-oil production, and in extending the field's life. The project may still be effective for the field for the next several decades. With this successful experience, many other operators have been triggered to make a start at least EOR initiative by performing laboratory researches and field trials. The initiation has been fully supported by various research and higher education institutions. For the time being, the most common methods to be experimented for implementation are chemical and gas injection especially CO_2.

3.1.5 CO_2 sources availability

Gas injection has long been successfully applied for enhancing oil production. In the USA, gas injection accounts for nearly 60% of EOR production. The gas injection EOR technique that is very much attracting nowadays is CO_2-EOR. First tried in 1972 in Scurry County, Texas, CO_2 injection has been used successfully throughout the Permian Basin. CO_2 gas in this case has been proved to be the most effective and economical gas to be injected to improve oil recovery. The main reasons for that would probably be the gas availability with relatively low cost. Fortunately, natural CO_2 sources and anthropogenic sources are hugely available in Indonesia. For example, East Natuna has abundant CO_2 sources with the total resources of approximately 157 TCF (Hanif et al., 2002). This CO_2 resource is much larger than the original CO_2 in-place of McElmo Dome, Bravo Dome, Sheep Mountain, and St Johns in the USA combined which is only about 90 TCF (Dipietro et al., 2012). Other huge natural CO_2 sources are located in South Sumatra and East Java Basins (Muslim et al., 2013). The anthropogenic sources are plentiful from the industrialised areas. Regardless their potential as CO_2 sources in the future; however, the anthropogenic gas utilisation requires further intensive research because the high cost for separating the CO_2 from other gases and solid particles affects the project economics considerably.

3.1.6 Domestic chemical products

There are currently several domestic chemical products that can be used for EOR applications. Local universities such as Bogor Agricultural Institute, Gajah Mada University, and Bandung Institute of Technology have been collaborating with operating oil companies to produce such chemicals. For example, Bogor Agricultural Institute has been able to produce surfactant generated from palm bunch. The chemical price is estimated as $8,000 per ton which is much less expensive compared to $19,000 per ton of imported chemicals. Gajah Mada University has been successfully producing surfactant from crude palm oil (CPO). Their chemicals will be applied in Rantau Field in the near future (Balance Magazine, 2014). Also, Bandung Institute of Technology has long been producing surfactant for EOR called Semar, an abbreviation from ‘solution by chemical modifier to accelerate oil recovery’. Their chemical mechanism is to reduce properly the oil viscosity in reservoirs for crude oils of less than 20°API. Semar has been proved to provide a success in reducing oil viscosity from 253 cp to 2 cp at 60°C. This reduction is better than that of steamflooding mechanisms. In reducing oil viscosity, the steamflooding requires reservoir temperature between 300–350°C. Semar will be applied in the near future for field trials at several fields including Bajubang, Bentayan, and Sungai Lilin in order to prove its performance (Balance Magazine, 2014).

3.2 Barriers

3.2.1 Mature fields, depleted pressure, high water cut, and lack of data

Indonesia has more than 650 oil fields located in both onshore and offshore. The fields hold a large number of oil resources. PT. Pertamina EP, the national oil company, operates the largest number of fields. The total number of fields currently operated by PT. Pertamina EP is 183 fields composing 124 producing fields and 59 non-active fields. These fields are spreading from North Sumatra in western part of the country to Papua in the eastern part. About 95% of these fields are categorised as mature. The total oil production has been declining at the rate of between 5%–20% per year since several years ago. The reservoir pressure in majority of the fields is depleting where most of the reservoir pressures are currently below the bubble point. Due to its maturity state, a lot of oil producing wells has been experiencing high water cuts and some of them became non-active fields. Almost all of these fields were discovered more than 40 years ago and typically have lack of data, old facilities, depleted pressure, low reserve, high water cut, missing production data, limited core data, and limited logging data (Aprilian et al., 2003a, 2003b; Kurnely et al., 2006).

3.2.2 Huge capital investments

Extra investments including huge capital and operational expenditure are required to develop EOR projects in mature fields. These include cost for rejuvenating production infrastructure and building other new facilities. Activities from laboratory studies to field implementation usually take long time resulting in significant additional costs. After full implementation is executed, the production response often does not occur immediately. During the time, the operating company must spend much more resources and efforts. As a matter of fact, Duri Field had been operating steamflooding for approximately nine years from 1985 to 1994 before achieving its peak production late in the year 1994 (Sutadiwiria and Azwar, 2011).

3.2.3 Chemical costs

Material cost is one of the most affecting factors in chemical-EOR economics. For example, the chemical injection project in Minas Field required a total cost of approximately $110/barrel of oil produced. This cost consisted of $30/barrel for polymer, $70/barrel for surfactant, and $10/barrel for facilities (Balance Magazine, 2014). Nowadays, chemical cost is the main concern in EOR economics since the chemical is usually imported. Despite the fact that based on depth and oil gravity being considered almost 80% of the reservoirs in the world is favourable for CO_2 injection, many Indonesian mature fields are suitable mainly for chemical injections. In this case, SKK Migas predicted the total amount of chemicals required for current Indonesian chemical EOR projects to approximately 8 million tons (Balance Magazine, 2014).

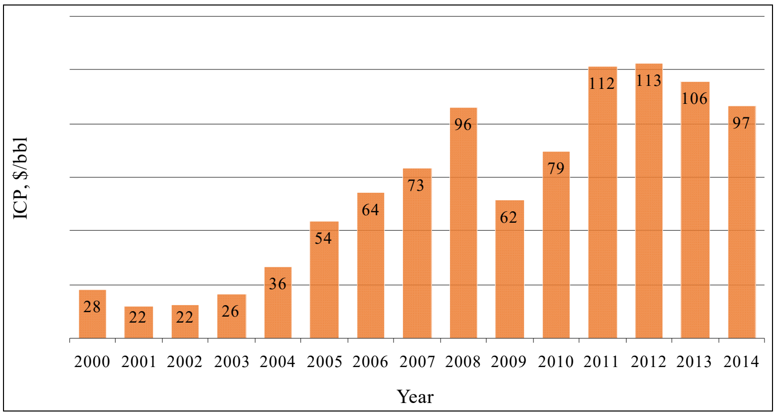
3.2.4 Oil price effects

The oil price strongly affects the petroleum industry activities. The lower oil price will reduce budgets spent for activities including research, field development, capital investment, employment, and exploration (Inikori et al., 2001). EOR operational activities also depend strongly on royalty and tax advantages (Farouq Ali and Thomas, 1996). Thus, decisions on the EOR to be implemented will not only be based on the technical criteria but also the oil price. The economy in this case obviously plays an important role in whether an EOR project can be implemented. EOR activities generally increase when the oil price increases and vice versa. For example, in early 1980s when the oil price was as high as $50/bbl, the EOR activities increased as well. In 1994, the EOR activities have fallen down to a lower level owing to the lower oil price. At that time, the oil price was below $20/bbl (Taber et al., 1997). According to a government report, the Indonesian crude oil price (ICP) had been essentially increasing during 2001 to 2013 (MEMRRI, 2014a, 2014b). However, as can be seen in Figure 6, the oil price has dropped below \$100/bbl since late 2014. EOR activities will accordingly be worse in the years to come if the oil price continues to fall.

3.2.5 Lack of experts

The implementation of EOR is quite complicated in field scales (Farouq Ali and Thomas, 1996). This circumstance is obviously different from that of laboratory scales. The EOR field implementation requires special operational expertise and skills to solve the complicated field scale problems. Lack of skilled experts for designing the implementation of EOR is currently one of major problems in Indonesia. Numerous existing experts are currently working for multinational oil companies overseas. This situation is most likely due to the big gap in the salary between companies operating in Indonesia and overseas (Balance Magazine, 2014).

Figure 6 Indonesian crude oil price (see online version for colours)



Source: MEMRRI (2015)

4 The future

4.1 Thermal method

Steamflooding has been proved to be able to improve oil recovery in Duri Field for more than 30 years. The field has long been the largest oil producer under steamflooding in the world. According to a recent survey, the world total oil production from steamflooding projects is estimated as 988,000 BOPD while the oil production from Duri Field is approximately 190,000 BOPD. Thus, the contribution of the field is about 20% (Koottungal, 2014). In terms of national EOR production, steamflooding will still be the leading EOR method in the future. However, this method is favourable only for heavy-oil and shallow reservoirs. Duri Field is currently the only field having reservoirs with those characteristics in the country so that the steamflooding project has not been expanded to other heavy-oil fields.

4.2 Chemical method

Chemical EOR is developing rapidly in recent years. Several leading universities and oil companies are collaborating in order to find the best chemical formulas that are suitable for any reservoir conditions. Bogor Agricultural Institute, Gajah Mada University, and Bandung Institute of Technology have been producing chemicals for particular reservoir conditions (Suryo and Murachman, 2001; Balance Magazine, 2014). Chemical injections field trials, field tests, and pilot projects have been implemented in recent years for more than 8 fields (SKK Migas, 2012, 2013; Hadiaman et al., 2011; Bou-Mikael et al., 2000; Rilian et al., 2010; Zulfikar et al., 2014; Wibowo et al., 2007). Results suggested that chemical injection is one of the promising EOR methods to be successfully implemented in the near future. Accordingly, there is a high hope that the method becomes the new way for improving oil recovery.

4.3 Gas method

Gas injection had been successfully implemented in Handil Field several years ago. Due to some particular reasons, the project has not been well developed further (Gunawan and Caie, 1999). However, studies on gas injection including CO_2 flooding have been continuously conducted until present days (SKK Migas, 2012, 2013; Santoso and Tjiptowiyono, 1997; Suarsana et al., 2005; Brioletty et al., 2005; Abdassah et al., 2000; Tobing and Sugihardjo, 2005; Janitra et al., 2012). Gas injection method is currently under examination through laboratory work, simulation, and field tests. It seems that the method still requires further research work that may take long time prior to full implementation in the field.

4.4 Microbial, seismic vibration and electrical EOR methods

Microbial, seismic vibration and electrical EOR methods are still immature to be implemented in the near future. Even though some efforts have been done in laboratories as well as in the field for testing (Kadarwati et al., 1999, 2001; Halim et al., 2008; Ariadji, 2005; Kurnely et al., 2006; SKK Migas, 2014), the methods have not yet provided convincing results for their ability in improving recovery and their feasibility in field-scaled implementation. For some reasons, the methods seem only favourable during laboratory work but may be difficult to implement in the field. In this case, the methods still need enhancement to ensure their implementation in the future.

5 Conclusions

Energy demand and oil consumption are increasing very rapidly every year in Indonesia. Oil production as the major energy source of the nation has been declining since 1995 because of the maturity of the fields. This has caused the government to import oil since several years ago.

The production stages have been mainly primary or secondary recovery. Meanwhile, exploration activities have not been able to discover new giant fields like Minas and Duri Fields. Most of the approximately 650 fields are then getting mature and at the same time the oil reserve and production are being depleted rapidly. In such the case, huge remaining oil in-place left by the primary and secondary production stages has led the EOR method as the best way to improve oil production.

Steamflooding is currently the only leading and proven EOR method implemented in Indonesia. The well establishment and successful implementation of steamflooding has encouraged operators to apply other EOR methods in their fields. Methods such as chemical injection, gas injection, microbial, seismic vibration, and electrical have been studied and developed extensively through laboratory works, simulation studies, field tests, field trials, and pilot projects.

Chemical injection is one potential EOR method to be implemented in the near future. One of major barriers in implementing the method is the chemical cost. Therefore, universities and research institutions have been collaborating with oil companies to produce local chemicals such as surfactant and polymer.

Another method that has been proved to be potential in both laboratory works and field tests is gas injection. While screening studies proved that CO_2 injection is the most favourable gas injection method to be implemented in the future, CO_2 gas natural as well as anthropogenic sources are abundantly available.

Microbial, seismic vibration and electrical EOR methods have also been considered potential at least in laboratory. However, these methods have not been well established and therefore are still immature to be implemented in the near future.

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