How Technology Increases Oil Production

Phil Hart, June 2008

How can you double something and still have ten times less than you started with?

The answer to this question will help us reassess claims that advances in oil field technology will postpone the peak in global oil production. The question itself arises from a case study of Enhanced Oil Recovery in the Handil Oil Field in Indonesia.

The Handil Oil Field

Handil is a giant oil field in the Mahakam Province of Indonesia, discovered in 1974 and still operated by 'TOTAL Exploration and Production Indonesia'. The International Society of Petroleum Engineers had a feature article on 'Reviving the Mature Handil Field' in the January 2008 addition of their Journal of Petroleum Technology [1].

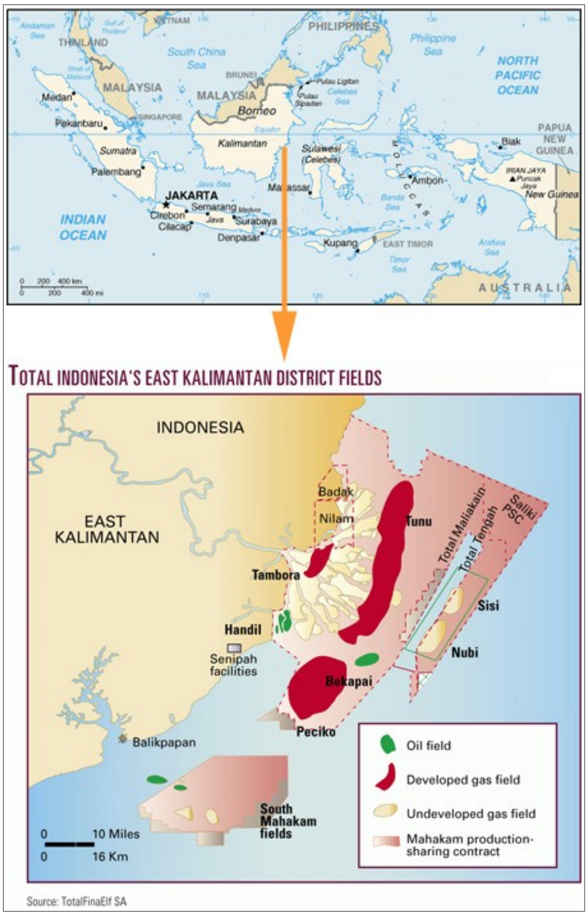

Figure 1: Location of the Handil Oil Field
Source: Wikipedia and LNGplants.com

From the JPT article:

- The Handil field comprises 555 unconnected accumulations (reservoirs) in structurally stacked and compartmentalized deltaic sands.
- The reservoirs are trapped by the Handil anticline, which is cut by major impermeable fault dividing the field into two compartments: north and south.
- The reservoirs are between 200 and 3500 meters subsea and cover an area 10km long by 4km wide.

Table 1: Handil Oil Field Characteristics

Ultimately Recoverable Resource	**~ 850 million barrels**
Porosity	**5-36%**
Permeability	**10-2000 millidarcies**
API Gravity	**43.9**
Sulphur	**0.052**

API and Sulphur from this *Handil Crude Oil Assay*

Table 2: Oil Production Summary at end of 2002

Cumulative Total Oil Production	**818 million barrels**
Natural Depletion	**261 million barrels (32%)**
Secondary Recovery	**549 million barrels (67%)**
Enhanced Oil Recovery (EOR)	**8 million barrels (1%)**

Oil Recovery

Before proceeding, it is important to understand the basic mechanisms of recovering oil from a reservoir:

Pressure on the fluids in a reservoir rock causes the fluids to flow through the pores into the well. This energy that produces the oil and gas is called the *reservoir drive* [2].

Primary Recovery is the oil produced by the original reservoir drive energy. The two most important natural reservoir drive mechanisms are Gas Depletion and Water Drive:

- **Gas Depletion Drive:** In the subsurface, the oil is under high pressure and has a considerable amount of natural gas dissolved in it. When a well is drilled into the reservoir, pressure in the reservoir decreases and gas can bubble out of the oil. A gas cap can be formed by gas bubbling out of the oil. Dissolved gas drive is very inefficient and will produce relatively little of the original oil in place from the reservoir. While this drive mechanism is commonly used to produce gas fields, rarely would it be relied upon for oil production alone.
- **Water Drive:** Water Drive reservoirs are driven by the expansion of water adjacent to or below the oil reservoir. The produced oil is replaced in the reservoir by water. An active water drive maintains an almost constant reservoir pressure and oil production through the life of the wells. The amount of water produced from a well sharply increases when the water reaches the well. The recovery of oil in place from a water-drive reservoir is relatively high.

It depends highly on the type of reservoir drive, the viscosity of the oil and permeability of the reservoir, but primary recovery produces on average 30-35% of the oil initially in place (OIIP), although it can be as low as 5%. Generally this leaves a considerable amount of oil in the reservoir, so additional recovery techniques may be employed:

Secondary Recovery: This involves injecting water into the field through injection wells. It can be initiated before or after the natural reservoir drive has been fully depleted. The aim is to use the water to sweep some of the remaining oil to producing wells. A waterflood can recover anything from 5-50% of the remaining oil in place that would not have been produced using primary recovery alone. The actual amount achieved depends enormously on the properties of the particular field.

Tertiary Recovery (Enhanced Oil Recovery): In some cases, where Secondary Recovery still leaves a significant amount of oil in place in the reservoir, enhanced oil recovery may be effective. Enhanced Oil Recovery (EOR) includes thermal, chemical and miscible gas processes - injecting substances into the reservoir that are not naturally found there.

Secondary Recovery techniques have been widely used since the early days of the industry. They are already in place in almost all fields where it is necessary or effective.

The history of Tertiary Recovery also goes back more than half a century. Tertiary Recovery, however, is only effective for a narrow selection of fields and involves substantially higher costs and effort.

Lifecycle of a Giant Oil Field

In their 1986 assessment of the world's 500 "Giant Oil and Gas Fields", Carmalt and St John [3] ranked Handil number 303 with an estimated 800 million barrels of ultimately recoverable oil. We can see that this 20 year-old estimate is very close to the mark in terms of the amount of oil produced with primary and secondary recovery (see Table 2). This should give us increased confidence in the Carmalt and St John estimates for other giant fields, including those in Saudi Arabia and other OPEC countries where current data transparency is inadequate.

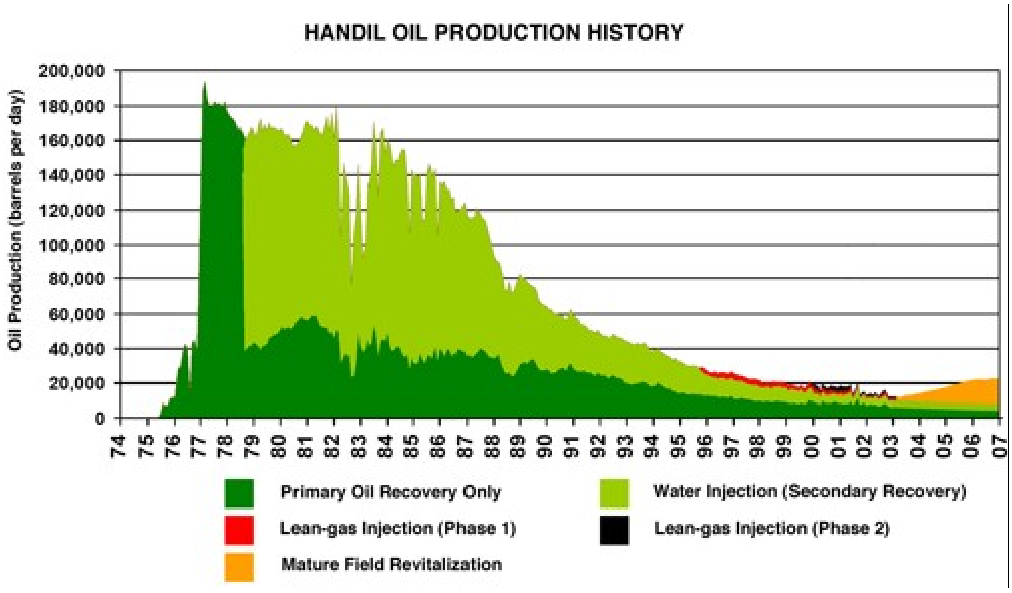

Figure 2: Handil Oil Production History
Adapted from this Presentation: [Mature Kutei Basin of Indonesia]

> *JPT:* To maintain production and reservoir pressure, water injection was started in 1978 which maintained the 160,000 BOPD production until 1985.

The production profile here presents a common picture of the lifecycle of a giant oil field. Secondary recovery (water injection) is used to maintain an oil production plateau for as long as possible before more significant decline becomes inevitable. After that, owners of the field have to decide whether intensive efforts to study, develop and apply tertiary (enhanced) recovery will recover enough additional oil to make it economically attractive.

Mature Field Revitalization

> *JPT:* In November 1995 a lean gas injection project was initiated in five reservoirs. The project boosted the production of the five large reservoirs and altered the overall decline rate of the field. Therefore, the project was extended in 2000 to six other large reservoirs, which resulted in more than 25 per cent of the field reserves being under a tertiary-recovery mechanism.

> *Tom Standing (ASPO USA Newsletter, November 5, 2007):*
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> Oil extraction by miscible gas injection goes beyond conventional pressure maintenance by injecting a gas with specific properties, at pressures sufficient to create a highly mobile gas/oil fluid phase that swells and fills pore space in the reservoir rock. Compression energy from the surface pushes this miscible phase toward wellbores. Injected gas cannot be chemically reactive in the reservoir.

Of the 8 million barrels produced using enhanced recovery mechanisms up to 2002, 6 million was from Phase 1 Lean Gas injection and 2 million from Phase 2 Lean Gas injection. Spurred on by their early success with lean gas injection, TOTAL kicked off a bigger campaign of 'Mature Field Revitalization' in 2003, including the following activities:

- **Dynamic Modeling and Sweet Spot Mapping:** Dynamic computer models combined with well logs and other static historical production data are used to identify the location of bypassed oil and smaller undrained areas of reservoir.
- **Light Workovers (LWOs):** Well interventions performed without pulling the completion at the bottom of the well. These LWOs are used to isolate water producing zones and target prospective new reservoir sections.
- **Infill Wells:** Where a Light Workover cannot be used because of the condition of the well, drilling new wells recovers the potential reserves in areas identified by Sweet Spot Mapping.
- **Enhanced Oil (Tertiary) Recovery and Optimization:** Miscible Gas Injection (described above), in this case using natural gas, is injected into the crest of the reservoir and attempts to sweep oil that has been bypassed toward the producing wells.

> *JPT:* In 2005, 26 LWOs were performed, of which 19 were successful. The project resulted in 1.7 million STBO (stock tank barrels of oil) production during the year and 4 million STBO of incremental reserves. The total cost was approximately USD 2 million.

The stated costs for LWOs yield a figure of $2 per barrel added as reserves - very economical but the potential is of course very limited (production costs are in addition to this). The more expensive infill wells were used for shallow reservoirs with heavy oil, or multi-lateral wells to target multiple small reservoirs which did not justify single wells previously.

The Results

Hopefully it is clear that what is simply described as 'Mature Field Revitalization' comprises many years of technically challenging study and modeling followed by intensive application in the field. For the engineers and geologists involved this was no doubt rewarding work. While all of these activities can be considered the application of 'new technology', only the final step is considered Enhanced Oil Recovery.

> *JPT:* These key elements increased the production from 12,500 BOPD in 2003 to 23,000 BOPD in 2007.

For a substantial investment of time, money and effort in the giant Handil oil field, we gain just 10,000 barrels per day of oil production. Yet this case study has appeared in the Journal of Production Technology because it is a prime example of what can be achieved (the two other case studies in the same issue showed only very mediocre gains). While there will be isolated fields that perform better, there will be many more that fail to make the pages of the Journal of Petroleum Technology because they provide far less spectacular returns. In many cases, after intensive appraisal and assessment the schemes never get off the drawing board.

> *Tom Standing (ASPO USA Newsletter, October 1 2007):*
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> An aspect of EOR that is seldom discussed is that recovery processes target oil fields with highly specific properties of reservoir rock and fluids. In brief, EOR processes are not universally applicable. With long years of research and field trials, the industry has developed two categories of EOR success.
>
> - Thermal methods in highly permeable reservoirs containing heavy viscous oil
> - Carbon dioxide or nitrogen (or natural gas) injection at miscible pressures in reservoirs with poor permeability
>
> The vast population of oil fields with light oil and good permeability generally have not responded to EOR efforts [because Secondary Recovery alone is already highly effective].

The Impact of Technology

TOTAL would be pleased if their efforts with the Handil oil field can increase the ultimate amount of oil recovered by even 5% (40 million barrels) compared to primary and secondary recovery alone. A 10% increase in this case looks unlikely. The returns look pretty small when averaged across the world's oil fields, given that only a proportion of them deliver a reward for this kind of effort.

While these aspects of 'advanced oil field technology' can increase production from particular oil fields, thereby attractively increasing profits for the owner, they do not significantly alter the picture of global oil resources.

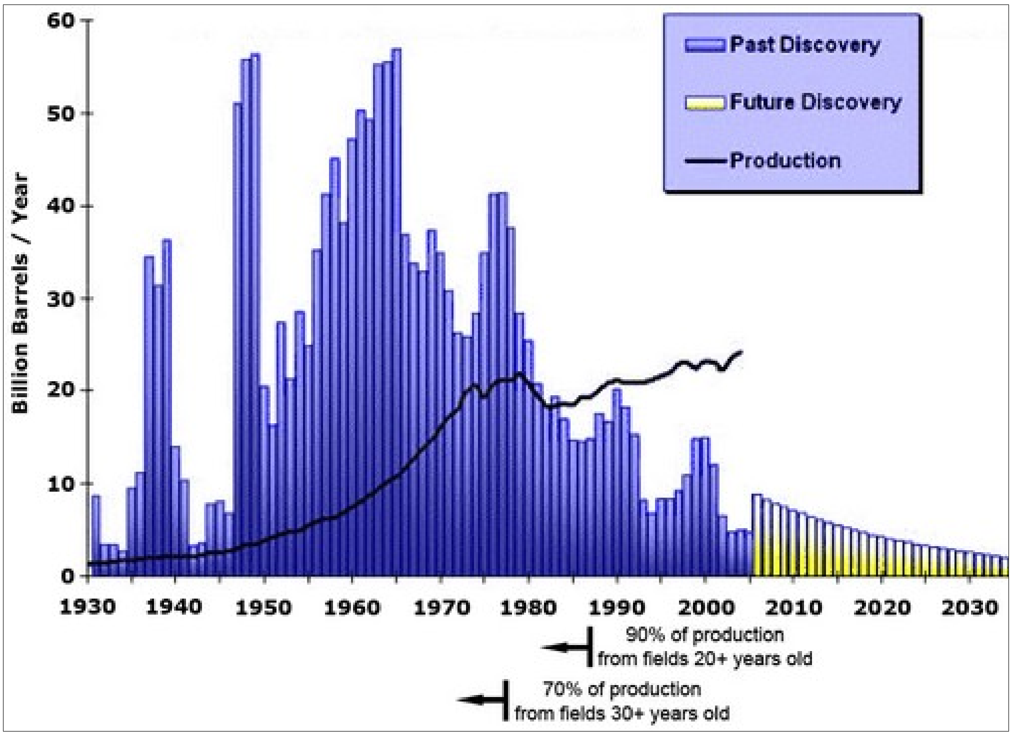

Figure 3: World Oil Discovery and Production

The Law of Diminishing Returns

Economists seem to have trouble understanding geological and technical limits to oil production, but they should understand the law of diminishing returns (Wikipedia):

> According to this relationship, in a production system with fixed and variable inputs, beyond some point, each additional unit of variable input yields less and less additional output. Conversely, producing one more unit of output costs more and more in variable inputs.

In our case we have finite, bounded oil fields. Until the mid 1980s, discovery of new oil fields exceeded our consumption rate, so there was little need to increase recovery from existing fields. As the discovery rate declined, companies had greater motivation to extract more from their existing fields. While at first they found easy gains, in the last decade especially the amount of effort required has climbed and yet the returns are falling: is it any surprise that oil industry inflation is rampant?

Oil field reserves may have 'grown' 10-20 per cent since the Carmalt and St John assessment in 1986, but we should not expect the next 20 years to deliver the same gain. Discovery of new fields has tapered off to low levels and the easy pickings for increased recovery have already been had. Unconventional oil sources will yield similarly small returns for extraordinary amounts of effort. The numbers simply do not stack up for oil production continuing to expand for another decade against the decline in large mature conventional oil fields.

Summary

How can you double something and still have ten times less than you started with?

In the case of the Handil Oil Field, a concerted campaign to revitalize the field almost doubled production from 12,500 barrels per day in 2003 to 23,000 in 2007. Yet this field had once produced nearly two hundred thousand barrels per day.

This is a representative picture of the role of technology and enhanced oil recovery: merely extending the tail end of production in oil fields that are well past their own peak in production.

So while the Society of Petroleum Engineers and other optimists tell us that technology and enhanced oil recovery will delay peak oil, a more objective look at the data suggests that production declines are relentless and they are stacking up much faster than incremental technological gains.

Phil Hart studied Materials Engineering at Monash University in Melbourne, before spending five years with Shell UK Exploration and Production. He was a project engineer for two new North Sea oil and gas field developments, then joined the Brent field maintenance team as a corrosion engineer. In 2006, Phil returned to Melbourne and is a member of the Australian Association for the Study of Peak Oil.

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References:

[1] Denney, D. "Reviving the Mature Handil Field: From Integrated Reservoir Study to Field Application", Journal of Petroleum Technology, Society of Petroleum Engineers, Houston, January 2008.

[2] Hyne, Norman J., "Nontechnical Guide to Petroleum Geology, Exploration, Drilling, and Production". PennWell Corporation, Tulsa, Oklahoma, 2001.

[3] Carmalt, S. W., and St. John, B. "Giant oil and gas fields," in M.T. Halbouty, ed., Future petroleum Provinces of the World, Memoir, 40, AAPG, Tulsa, Oklahoma, 1986.

[4] Mature Kutei Basin of Indonesia: http://www.ccop.or.th/PPM/document/SEM2/Indonesia.pdf