Application of Secondary Recovery
Methods to Japan's Oil Fields*

by Wilbur H. Somerton**

Introduction

The petroleum industry in Japan has made great progress in the past few years and everyone engaged in the industry from the field worker up through the company director should be complimented for their untiring effort. This industry, although small in comparison to other industries in the country, is vitally important to the economy of the nation. Continued unceasing effort must be made not only to maintain but also to increase the production and reserves of petroleum and natural gas. The exploration program in Japan has accomplished a great deal in this connection and promises to continually increase production and proven reserves. Yet there exist in Japan at the present time, vast reserves of petroleum which are not recoverable by normal production methods. It is regarding these proven but “unrecoverable” reserves that this discussion will deal.

By the application of primary production methods, only 25~50 percent of the total petroleum in a reservoir is produced. This means that at the end of the normal producing life of a reservoir and at the time of abandonment, 50~75 percent of the original petroleum remains in the reservoir. The purpose of secondary recovery is to produce as much of this remaining petroleum as is possible. It is estimated that in the United States as much petroleum will be produced by secondary recovery as the total produced to date by primary recovery methods. This may not be the case in Japan because petroleum shortages have caused the depletion of reservoirs to a lower

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** Professor of Petroleum Production Engineering, University of California, Berkeley, California.
residual petroleum content. Perhaps only one-half as much petroleum will be recovered by secondary recovery as was produced by primary recovery, but ever this represents a large amount of petroleum. Every effort must be made to produce this supply of petroleum and the following is a review of how this might be accomplished.

**Review of Principles and Methods**

Petroleum is caused to be moved from the reservoir to the oil well borehole by three well known forces—water pressure, gas pressure, and gravity. An oil well stops producing petroleum when these forces are no longer effective in moving oil from the reservoir, and the well must be abandoned. By the application of secondary methods, more energy in the form of water or gas under pressure, is added to the reservoir to cause renewed movement of petroleum to the well bore. Secondary recovery is defined as “recovery which results from the addition of energy to the native reservoir energy as by the injection of fluids”. This definition is not complete, however, because other methods such as oil-mining, are also secondary recovery methods. In the case of oil mining such as at Higashiyama, no energy is added to the reservoir but the force of gravity is made more important.

Water-flooding is a method of secondary recovery in which water under pressure is forced into the reservoir through an injection well. This injection water causes movement of petroleum away from the injection well toward producing wells. By the proper application of water-flooding, the entire reservoir can be flooded or washed by water and a large part of the residual petroleum can be produced. The water is generally injected into wells low on the structure and the oil driven or floated upwards to the structurally higher producing wells.

Gas-injection is a method of secondary recovery in which gas under pressure is forced into the reservoir through an injection well. In this case, gas is usually injected into wells on or near the top of the structure and petroleum forced down-dip to structurally lower producing wells. Gas-injection generally does not recover as large a percentage of the residual petroleum but the method is somewhat less expensive if gas is available at a reasonable cost. A reservoir can also be water-flooded after gas-injection to recover additional oil. The nature of the reservoir and the economic factors involved will
determine which method, water-flooding or gas-injection, will be more profitable.

Other methods of secondary recovery should also be considered. These include oil drainage through mine openings such as at Higashiyama, the actual mining and washing of oil sands, the generation of gas from depleted oil sands by the application of heat, and other yet untested methods. In reservoirs now producing little petroleum but large amounts of water, secondary recovery methods as such not be applicable but careful study of wells and their may production characteristics may make possible the recovery of additional petroleum by proper well control.

Application of Secondary Recovery Methods in Japan

The direct application of secondary recovery methods, as practiced in the United States at the present time, to Japan's oil fields may not be possible. These methods may require modification because of certain special circumstances which exist here. These problems include: lower residual oil content, poor condition of many wells, lack of subsurface information, and the relatively high cost of drilling and equipping wells. These problems are not impossible to solve and must be solved if recovery of this valuable supply of petroleum is to be attained. So, although full advantage must be taken of past experience in secondary recovery, considerable experimentation and development will be necessary.

In the application of secondary recovery methods, the reservoirs must be carefully studied and those best suited for the purpose should be selected for experimentation. The methods developed and experience gained may then be applied to less suitable fields with greater chances of success. Some of the matters which should be investigated include: drilling of small diameter injection wells cemented to the surface and completed by gun-perforating; simple injection-fluid treatment methods; the possibility of either flowing or gas-lifting producing wells to save the expense of pumping; methods of repairing old wells so that only a minimum of new wells need be drilled; and many others. Fundamental research should also be carried out to develop new principles which may lead to more successful operations.

The preliminary development work will be costly and it is hoped
that in the new Petroleum Resources Development Law, provision will be made for government assistance. Some form of assistance may be needed to encourage petroleum producers in undertaking this preliminary work. After this preliminary experimentation and development work, aid should not be necessary and petroleum producers will find secondary recovery profitable.

To assure success and profit to all producers there must be cooperation. All producers in a common reservoir must work and plan together to obtain the greatest profit for all and to conserve the nation's supply of petroleum. Engineering committees with fair representation of all petroleum producers in the reservoir should work together to form an "operating agreement". This operating agreement must protect the interests of the small petroleum producer and yet permit the application of the most efficient methods.

**Summary and Conclusions**

1. In Japan there exist large reserves of petroleum which cannot be produced by primary recovery methods.
2. Secondary recovery methods must be developed and applied so that these reserves of petroleum can be produced.
3. Methods of secondary recovery in use in the United States may have to be modified and improved in their application to Japan's oil reservoirs in order to realize the greatest profit.
4. Some governmental assistance may be required in the preliminary experimentation and development stages of a secondary program.
5. Cooperation of all petroleum producers in a common reservoir will be necessary to realize the greatest profit to all.
6. The Secondary Recovery Committee of the PRDPC will serve an important function in guiding operators in the development and improvement of methods and this Committee should be given full support by all concerned.

**Summary of Discussion from Floor**

1. Question: In water-flooding is the water always injected below the edge water-oil boundary?
   Answer: No. The location of water injection wells depends upon the structural conditions and formation thickness. If the formation is comparatively thin and the structure is comparatively flat,
"blanket" flooding, as typified by the 5-spot pattern, is generally more applicable. Where the formation is thick and variable in character and the formation dips at a considerable angle, more efficient flooding can be realized by injecting water into structurally lower wells.

2. Question: Is it practical to heat injection water to reduce oil gravity and viscosity?
   Answer: No. Calculations have shown that the cost of the heat energy required is greater than the benefits derived.

3. Question: What percentage of injection wells are newly drilled in the United States?
   Answer: Although no figures are available, it is believed that most water injection wells are newly drilled. It is felt that in many cases old wells could have been satisfactorily reconditioned at a much lower cost.

4. Question: What is the current maximum depth of water flooding?
   Answer: Water injection to maintain reservoir pressure is being applied to the deepest reservoirs. The limiting depth of waterflooding, if there is a limit, is not known. At the present time reservoirs of 5,000 feet in depth are being water flooded.

5. Question: Would channeling result if water were injected into an old well which had produced considerable sand and probably has a greatly enlarged borehole?
   Answer: It is difficult to answer this question but it would appear that in a uniform sand body, enlargement of the borehole would have little effect on channeling. If the formation is non-uniform and if enlargement is confined to certain looser parts of the formation, some effect would be noted. Water would enter the enlarged portion of the formation in larger volumes because of the greater area per unit thickness of formation exposed.

6. Question: Is secondary recovery applicable to gas fields?
   Answer: Not in the general sense; however, in the case of the Mobara gas fields, produced water might profitably be reinjected to maintain reservoir pressure and well productivity.

7. Question: Discuss the practice of flowing water-flood production.

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Answer: Where reservoirs can withstand the injection pressures necessary to cause flow of producing wells, without causing "lifting of the overburden" and resultant channeling, flowing water-flood production has proven more efficient than pumping. The expense of equipping and maintaining production wells is lower and the ultimate recovery is believed to be higher.

8. Question: What is the maximum limit of injection pressure?

Answer: The maximum limit of injection pressure, called the "critical pressure" is the pressure at which the injection pressure-injection rate relation deviates sharply from the normal trend, this deviation being in the direction of increased injection rates. At the "critical pressure" some physical change occurs in the formation causing channeling of the injected water. This change might be a result of lifting the overburden but is probably a result of compaction or fracturing of weaker formations.

9. Question: What is the lower limit of permeability, porosity, thickness and oil gravity for successful water flooding?

Answer: The lower limit of these properties for secondary recovery is probably in about the same range as for primary recovery. Formations with permeabilities as low as 10−50 millidarcys are being flooded effectively. Porosity and thickness must be considered from the standpoint of reservoir storage capacity. Thus these two values must be sufficiently large to give a resultant storage capacity of such magnitude as to make recovery therefrom practical. Oil with a gravity as low as 16° API has been successfully recovered by water flooding.

10. Question: Is selective plugging successful?

Answer: Selective plugging to improve the injection characteristics of a well has been successful in formations having a relatively low permeability range. The plugging is generally not permanent but must be repeated periodically. In the case of sands having higher permeabilities, comparing to those in California and Japan, selective plugging has been totally unsuccessful to date.

11. Question: Why is gas injection generally less expensive than water injection?

Answer: In cases where abundant gas is available at a low cost, gas injection is less expensive than water injection. The princi-
pal reason is that gas does not have to be treated for injection where as a large part of the expense of water injection has been in water treatment. If gas becomes scarce and water taremt is simplified, the difference in cost will become very small. A second factor reducing the cost of gas injection is the fact that the gas does not lose its value after injection because a large amount of it can always be produced and sold at a profit.

12. Question: What well spacing and injection rates are commonly used in water flooding?

Answer: These values are highly variable depending on reservoir conditions, existing well spacing, desired flood-out time, and in general the policy of the particular operator. Commonly spacing between injection and producing wells ranges between 215 and 660 feet. Rates of injection range between one and ten barrels of water per foot of sand per day.

(以下に掲げるのは上の譯文である)

日本油田に於ける二次回収法の適用に就て

天然資源局石油課 サ マ テ ト ノ

緒 言

日本の石油産業は最近数年間に長足の進歩を遂げた。これは現地作業に従事して居る職員及び経営者各自が不動の努力を傾注した結果によるものとして誇張すべきである。

現在日本の石油産業は他の重要産業に比較して御規模の点に於て大産業と称し得ざるも国民経済から見て非常な重要性を持つ産業の1つであることは勿論である。斯様な情勢下に於て日本の石油は現在の産油量を持続するばかりでなく、更に石油、天然ガス資源の埋蔵量増加及び増産に一段の努力を傾注しなければならない。

現在日本に於てこの産業に結びつけられた採鉱計画は大極なる効果をもたらし增産と石油の地下埋蔵量の確定が約束された。然しこれ日本に於て行われている採油方法に依っては既未回収の莫大の量に上る石油が地下に残存しているのである。この確定させる未回収残油を如何にして回収するか、現在の問題である。

一次産油方法に於ては其の回収率は全埋蔵量の約25~50%に過ぎない。換言すると普通の油層では統に於て猶地下に50~75%の石油が回収不可能として地下に残存しているのである。二次回収適用の目的は即ちこの地下に既つっている石油を如何にして有利的に採取するかにある。今米国に例を取って見るとこの二次回収法によって一次産油法に採取せし今日迄の総産量に匹敵する量を回收出来ると推定されている。斯様な回収率が其の如く日本に於て適用されるか否かは疑問である。何となれば日本の石油生産の不足は
油層の発現の原因となり残存石油量を少なくて居るからである。併し二次回收法の適用に依って一次採取法の1/3位は回收出来るであろう。併し之でも莫大な数値に於て多大の増産が期待されるのである。

斯様に残存石油の回收に関しては凡ての努力を傾注しなければならない。

次に如何にして此の二次回收法を行うかを概略的に述べる。

原理及び方法の検討

元来石油の地下油層より油井で集せる原動力は水に一般に知られている3つの力に依るものである。即ち水の圧力、瓦斯の圧力及び重力である。それ故にこの3つの機能が停止状態に陥ることによって地下に於ける油層より油井に向って移動しつつある石油は停止の状態に陥り遊には蒸油井は喪権井となるのである。二次回收法は即ち水又は瓦斯の圧力エネルギーを利用してこの圧力を地下の油層に高圧力の下に加えて油井の方向に石油を新しく移動せしめるのである。換言すると二次回收法と流動体の注入に依って元の油層に於ける圧力エネルギーに更に人工的圧力の援助を加えることである。

併しこの定義は完全ではない。何となれば他に今回回收法があるからである。例えば従来行われた東山油田の坑道掘採油法の様なもので斯の場合は圧力エネルギーを地下油層に注入するので無く重力作用に依る排油が主の動力として働くからである。

水攻法とは高圧力の下に水を圧入井を通じ地下油層に水を注入する方法である。即ち高圧力の下に水を注入して集油層中の残存石油を産油井の方向に移動させめる方法である。この適當なる水攻法の適用に依って集油層中の孔隙を充している残存石油全體が水攻を受け又は洗浄され相当の部分の石油が採取出来るものである。方法としては普通水を地質構造の下翼部に堅った圧入井を通じて注入し、漸次構造の頂部に追込み遂に地質構造の頂部の産油井迄浸水作用を行わせるのである。

第二の方法としては従来行われた瓦斯圧入法がある。其の原理に就ては水攻法と同様である。即ち瓦斯を高圧力の下に注入井を通じて地下油層に注入し残存石油の回收を計るのである。この方法に於ては水攻法とは反対に最初地質構造の頂部附近の圧入井に注入し而して漸次石油を地質構造の下翼部に於ての油井方向に移動せしめ回收を計るのである。元来瓦斯圧入法は水攻法と比較して其の回收率が少しひ若し産油地に於て利用し得る瓦斯があれば費用の点に於て有利である。

又瓦斯圧入法を適用し其の後則に水攻法に依つて残存石油の回收も行われ残餘の石油回收を計る事も出来る。斯様に地下集油層の状態及び地方の経済條件に即応し水攻法を適用すべきか又は瓦斯圧入法を採用すべきかを決定出来るのである。

其の他二次地下残余石油回收法として考慮すべきは従来東山油田にて行われた坑道掘採油法である。即ちトンネルを深く坑道を作り油層の排油を促せる方法である。此の他油砂の洗浄に依る採油法、加熱作用にて油層中に瓦斯を発生せしめ不可能油回收を回収せしめる法、其の他未だ実験していない方法等もある。現在産油は殆ど無く且つ多量の水を産出する油井に於ては二次回收法の適用が不可能であるかも知れないが併し詳細に渉る産油井の研究調査に依つて各井の特殊産油状態を知る事を前提として適當なる油井調節を行い程度の回收増大を現出出来るものと思われる。

日本に於ける二次回收法の適用

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現在米国において行われている二次回收法を日本の油田に応用して直に其効果を奏するや否やは疑問であるが、日本の特殊状態に適用出来る様に改良を加える事が必要である。此の理由を挙げると（1）残留石油量の低い事。（2）多数油井が貧弱なる状態である事。（3）地下油層の状態不明なる事及び比較的堅井費及び設備費の高値なる事の諸點である。

これ等の種々の問題は困難なる點ではあるが其の解決は不可能では無く又この重要なる石油の回收が必要と認められた時には解決せねばならない問題である。過去に於ける二次回收法の経験は充分に活かす必要は勿論あるが併し更に多くの試験と改良が必要となるであろう。

二次回收法の適用に於ては充分に地下油層の状態を探究し其の実施に當つては最善の方法を選択して其の結果を適當た油田に應用して最大の効果を上る様努力すべきである。

研究項目として取るべきものは（1）小口径の堅入井を掘井しチュービングをケーニングとする仕上及びとくに地元流連続セメントする方法。（2）簡単な流連處理法の採用。（3）ポンピングの費用を除去する為に自噴又はガスリフトの可能性の研究。（4）古い油井の改修方法を研究し堅井を最少限に止める事の研究等である。又新しい原理の発展の為基礎研究を遂行しなければならない。この基礎研究に依って新改良進歩の原因をもたらすからである。

基礎又は最初の試験的実施には多大の費用を要する。従故に新石油資源開発法に依り之に対する政府の補助を確保する様希望する。この最初の實行者に対しては或る形の補助が煉油業者を鼓舞する結果となるが、この試験完成後は更に補助を與える必要は認めない。何故ならば煉油業者は自らの二次回收法の實行が有利である事を其の時既に認め居るからである。

二次回收の成功と石油業者の利益確保には業者相互間の協力が無くてはならない。殊に同一油層に於ける二次回收実施に當つては相互に最善の利益を確保する事に協力し國家の石油供給と保存に協力すべきである。

概要及結論

（1）現在日本に於ては多大の石油が地下に於て残留されて居り従来の一途採油方法のみで之の回収は不可能である。

（2）この地下に於ける残留石油は二次回收法に依り確保する事が可能である。

（3）現在米国内で実行されつつある二次回收法を直に日本に適用する事は不適當であるが之を日本に適應する様改良すれば産油増加の實現は可能である。

（4）第二次石油開発法改正に際し最初の試験研究及び実地試験実施に於ては政府が或程度の補助をなす様考慮する可きである。

（5）同一油層の開釀に従事する石油業者は相互間の協力に依つて実施する方が利益である事を確認しなければならない。

（6）二次回收法の適用は國家の石油供給を増大する結果となる。

筆者は米国及び日本に於て行われるこの二次回收法の結果に就て相互に結果を交換し相互の知識増進を図る事である。何となればこの実施の結果は兩国の煉油業者に対し重要な参考資料を提供する事になるからである。