Design Aspects of Thermal Recovery Projects

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INTRODUCTION

Ten years age the name "Thermal Recovery" was usually applied to the forward combustion oil recovery process. Today, so many variations of oil reservoir heating methods have been proposed and tested that "Thermal Recovery" now has a far more general meaning. Any oil recovery process which depends upon application of heat to a reservoir is a thermal recovery process. This classification includes: (1) production well heating, (2) both forward and reverse combustion, (3) continuous hot-fluid injection (such as a steam or hot-water injection, (4) intermittent hot fluid injection (such as the push-pull steam injection), (5) use of nuclear devices, (6) electrolinking or electrocarbonization. Processes listed under items 2, 3, and 4 may also be classified generally as "fluid-injection" processes. The thermal recovery methods which appear to deserve immediate addition to the list of fluid injection methods presently evaluated include: forward combustion, push-pull steam injection, and continuous steam and hot-water injection. It is the purpose of this paper to summarize sources of design information available for these thermal recovery processes.

FORWARD COMBUSTION

A great deal has been published on the forward combustion process. Much information on the theory and mechanism of this pocess is available; much experimental information has been gained from both laboratory and field studies. See the bibliography of Ref. 1. In regard to design, two excellent papers by Nelson and McNeil summarize existing information on design of forward combustion and offer a step-by-step procedure.[2,3]

The Nelson-McNeil design method is based on a number of important conditions and observations. The reservoir is developed in large enough blocks that it can be assumed that all oil displaced by the process will be recovered at poducing wells. Oil displaced is composed of two important contributions: oil displaced from the "buried" sand, and oil displaced from unburned sand by gravity drainage, gas-drive, steam-drive, and other mechanisms caused by heating and effects associated with combustion. Quantitatively, oil displaced from the "burned" sand is equal to the initial oil content at the start of the project less the oil consumed as fuel in the process. Fuel consumed has been in the order of 200 to 300 bbl/acre ft. In regard to oil displaced from unburned sand, Nelson and McNeil observe that field tests indicate more than half of the initial oil content has been displaced during forward combustion. They recommend that oil displaced from unburned sand be estimated as 40 per cent of the initial oil content at the start of the project. This factor applies to both vertical and areal portions of the pattern not reached by the burning front.

In regard to the portion of the pattern volume which can be swept by the burning front, Nelson and McNeil report that vertical sweep efficiencies in field tests have ranged from 30 per cent to more than 90 per cent. They recommend an average value of 55 per cent be estimated if specific information is not available. As yet, no other specific information for estimation of vertical sweep efficiency is available. In regard to a real sweep, Nelson and McNeil report that 55 per cent is a practical estimate for the developed five-spot pattern. The product of 55 per cent areal sweep and 55 per cent vertical sweep leads to an estimated 30 per cent volumetric sweep efficiency for the developed five-spot pattern. This means that about 30 per cent of the pattern volume might be swept by the burning front. This factor may not be applied to estimate oil recovery directly however, because many effects associated with combustion lead to recovery of oil from the unburned portion of the pattern.

Nelson and McNeil also published criteria to establish the total air required and air injection rate. In regard to the total air required, it was recommended that sufficient air be allowed to burn the full interval thickness. This recommendation essentially doubles the minimum air required and allows for the field observation in some tests that oxygen may be produced during the operation.

The Nelson-McNeil combustion design criteria reviewed above essentially specify the oil recovery from a forward combustion project in terms of the oil saturation at the start of the operation, and the fuel concretration. Because + heir design method also leads to a constant air requirement per acre-ft of pattern, the method yields a constant injected air-produced oil ratio. Because a major cost factor in this process is the cost of air, the air-oil ratio should be computed before extensive design calculations are made. This factor alone usually indicates whether further consideration for forward combustion is useful. Reference 2 provides a detailed economic analysis of a sample combustion design project.

CONTINUOUS STEAM AND HOT-WATER INJECTION

Far less has been published on continuous injection of hot fluids for oil recovery than has been published on the forward combustion process. The idea of steam injection is quite old. An excellent account of a thoroughly-planned and executed field trial of steam injection in Texas was published by Stovall in 1934.[4] Although a number of papers appeared in the Russian literature concerning heat flow associated with hot fluid injection in following years, the next significant paper in the Western literature was in 1955.[5] The real start of modern interest in hot fluid injection might be dated with the 1959 paper by Marx and Langenheim[6] concerning growth of the heated volume in the reservoir, and potential oil recovery.

Basically, the important design problems associated with continuous steam or hot-water injection include: operation and cost of operation of the thermal unit to supply hot water or steam, heat losses during transportation of the hot fluid to the sand-face, heat loss from the heated formation, the volume of the heated formation as a function of time, and finally, the oil displacement from the heated reservoir. In addition to the above, there are other important considerations in this sort of operation. These include fuel and water supply, and mechanical problems associated with heating of tubular goods in hot wells.

In regard to the heat loss problems, sufficient information has been published to provide quantitative engineering information. Reference 7 provides a summary of existing information and tabulates sources of further information. In regard to oil displacement, Marx and Langenheim provide a straightforward method, although it has been necessarily simplified. William et. al. have presented a detailed account of laboratory studies of cold-water, hot-water, and steam injection results from flood-pot tests of a variety of sands and oils.[8] This paper is an excellent source of information, and provides the only detailed analysis of the oil displacement mechanism availabel. Willman et. al. also suggest a modified Buckley-Leverett calculation for field design purposes. This calculation is complex and best-suited to computer evaluation.

In both the Marx-Langenheim and Willman et. al. design methods, the endpoint is essentially controlled by the vertical heat loss from the heated formation. One of the most significant costs in this process is the steam or hotwater cost. Thus the end point is essentially set by an economic limit hot fluid-oil ratio.

Although a number of continuous hot-fluid injection tests have been carried out in the field, no detailed field test description has yet appeared in the Western literature. Thus test design must be carried out on the basis of engineering extrapolation at the present time.

INTERMITTENT HOT FLUID INJECTION

The greatest increase in field application of thermal recovery processes since the early 1960's has been in this category. This process has been called by many names. Among them are "push-pull steam injection", "steam-soaking", and "huff-and-puff steam injection". There are many variations on the process, although basically it involves injecting a batch (perhaps 2000 to 10,000 bbls feedwater) of about 80 per cent quality steam into a producing well, letting the well stand ("soak") for a few days, and then returning the well to production. This process has been described numerous times in the recent literature, and hear-say reports of remarkable oil rate increases mentioned.[9,10] One recent publication provides detailed information on field tests, but does provide cut data for the gross production.[11]

As yet, no publication concerning laboratory or field test results of a quantative nature has been presented. Indications are that field applications are being made on a trial basis with portable field heaters, and permanent installations made on the basis of this experience. The rapid growth of field application of this process results from the fact that results, if favorable, are quite rapid; and that trial costs are low. No information on the results of repeated cycles of injection has been published.

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