ENHANCED OIL RECOVERY USING AQUEOUS PHASE CHEMICALS, MISCIBLE GAS INJECTION, AND THERMAL MEANS

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Summary

Enhanced oil recovery (EOR) is any process that increases ultimate recovery of oil by the injection of fluids, chemicals, and heat energy not normally found in an oil reservoir. The most common injectants are gases such as steam and carbon dioxide. By implementing EOR, 30 to 70 % of the oil originally in place in a reservoir can ultimately be extracted compared with 10 to 50 % using primary and secondary recovery. In cases where the crude oil is particularly thick and viscous, EOR processes using heat, chemical solvents, or some combination of heat and solvents are the most feasible recovery processes for these difficult resources. EOR is usually categorized into thermal recovery, miscible gas injection, and chemical flooding; however, many promising processes combine aspects from two or more categories. EOR processes are generally aimed at modifying the mobility of the various oil, water, and gas phases in a reservoir. One factor contributing to mobility is phase viscosity and the mobility varies inversely with viscosity. Thermal recovery is usually implemented to produce thick viscous oils that do not flow well unless they are heated thereby reducing their viscosity. During miscible gas injection, a gas such as carbon dioxide is injected to mix in all proportions with reservoir oil, reduce oil viscosity, and sweep oil towards production wells. Chemical flooding seeks to improve the effectiveness of injected water at displacing oil. Chemicals such as water-soluble polymers raise the viscosity of water making it a more effective displacement agent. Often polymers are combined with surfactants (i.e., soap) to control the mobility of the injected water and to mobilize oil

left behind in water swept zones.

1. Introduction

Oilfield development is usually divided into primary, secondary, and enhanced oil recovery stages (EOR). During primary recovery, inherent reservoir pressure is utilized to produce reservoir fluids through production wells drilled in to the formation. When pressure is reduced at the wells, a pressure drop is established between the formation and the well. Fluids are driven into the well as a result of the pressure drop, or analogous pressure gradient. Over time, however, reservoir energy is depleted, the reservoir pressure declines, the pressure gradient decreases and consequently the oil production rate declines. Typical oil recovery associated with primary pressure depletion is 10 to 20% of the original oil in place (OOIP). Secondary recovery is the process of injecting a fluid, via so-called injection wells, to maintain reservoir pressure and drive additional reservoir fluids toward production wells. Water is the injectant of choice for secondary recovery due to its availability and low cost; hence, the process is often referred to as waterflooding. The cumulative oil recovery following secondary processes may be from 30 to 50% of the OOIP. Some origins of incomplete recovery are discussed in the next section.

Accordingly, the target of oil remaining after secondary recovery is substantial. In the United States alone, it is estimated that about 400 billion barrels of oil remain in the ground following secondary recovery. For reference, the U.S consumed about 7.6 billion barrels in 2006 and the world about 30 billion barrels in 2005. Hence, the remaining oil volume for the U.S. represents about one half of a century of oil supply at 2006 consumption rates. Unfortunately, worldwide estimates of the volume of oil remaining after secondary recovery are not readily available, but they are expected to be equally significant.

Although EOR is not always implemented, it is sometimes referred to as tertiary recovery because it follows secondary recovery. One problem associated with such a classification of recovery techniques is that many fields are not developed in this order. In cases such as heavy oil, where the oil is dense, viscous, and consequently oil does not flow easily into production wells, primary and secondary recovery processes may yield oil at uneconomic rates. In this case, a “tertiary method” that reduces oil viscosity in-situ, such as steam injection, might be applied without being preceded by primary or secondary recovery. Likewise, a reservoir might proceed directly from primary production to steam injection to avoid adding water to the reservoir that would later need to be vaporized in a thermal recovery project. Because these situations have become more common as production operations have shifted to difficult to produce reservoirs, petroleum engineers have generally dropped the term tertiary in favor of the more descriptive enhanced oil recovery (EOR). Hence, a functional, classification is primary depletion, waterflooding, and enhanced oil recovery. Mechanisms of lifting oil to earth's surface, e.g. pumping, do not play a part in the classification of oil-recovery processes.

To achieve enhanced recovery, fluids such as steam, carbon dioxide, aqueous solutions of soap and polymers, and heat are injected into an oil reservoir to increase the cumulative oil recovery. Hence, EOR is oil recovery achieved through the introduction of fluids, chemicals, and heat energy not normally found in an oil reservoir. Whereas this definition does exclude water flooding and reinjection of natural gas, it does not restrict EOR to a particular phase of a reservoir's life (i.e., primary, secondary, or tertiary). Note that injection is an inherent requisite of EOR.

Enhanced oil recovery is a subset of oil production techniques referred to as improved oil recovery (IOR). Along with the recognition that EOR processes might be applied very early in the life cycle of a reservoir, came the realization that there were many opportunities for improving oil recovery. The term improved oil recovery (IOR) came into use to signify a broad range of activities to further oil recovery. In addition to EOR, the field of IOR includes improvement in oil recovery through various means, including but not limited to, location of oil bypassed during primary and secondary recovery operations, drilling of more wells to produce this bypassed oil, optimal choices for the location of water injection into an oil reservoir, allocation of water for injection across a field so as to maximize oil recovery while minimizing produced water, and improved production engineering techniques such as hydraulic fracturing. IOR is not discussed in this entry.

At this time EOR processes contribute significantly to oil production worldwide, even though the majority of oil production remains in the primary or waterflooding phases. In 2005, EOR is attributed to the production of roughly 240 million barrels in the U.S. or about 12% of U.S. production. Enhanced production in Canada was more than 94 million barrels in 2005 and Indonesia produced 80 million barrels. China, Venezuela, Mexico, and Norway also have significant fractions of their oil production originating from EOR.

In addition to the hydrocarbon resource accessible via EOR, concerns regarding the release of anthropogenic carbon dioxide to the atmosphere are driving interest in carbon-dioxide based EOR as a means of storing carbon dioxide in depleted oil reservoirs. EOR has emerged as a potential contributor to mitigate atmospheric emissions while alleviating concerns over oil supply. Such carbon storage is frequently referred to as sequestration. The benefits of sequestration in oil reservoirs include revenue from oil recovered as well as reservoir volume to store significant amounts of carbon dioxide. Because hydrocarbon reservoirs have held oil and natural gas over geologic time, they are seen as potentially secure storage sites. Estimates of the sequestration potential of oil and gas reservoirs range from half to all of global carbon dioxide emissions for the next half century.

An additional recent driver for implementation of EOR is concern over so-called "peak oil." The Earth's oil resources are vast, but they are finite in volume. This has lead many to predict the volume of oil that is ultimately recoverable from the Earth and the year that worldwide oil production shall reach a maximum and then decline thereafter. Other peak oil concerns originate from the fact that the energy needs of developing countries are increasing and a significant fraction of this energy demand is oil. The most likely place to locate more oil is known oil fields. Hence, EOR methods provide a means to increase recovery from known fields thereby maintaining or increasing oil supply while at the same time reducing the costs and risks of finding and producing new hydrocarbon resources.

In the remainder of this entry, the inherent inefficiency of primary and secondary recovery processes is described. Subsequently, the important EOR categories of thermal recovery, gas injection, and chemical flooding are presented. Finally, example implementations of EOR are described. For further engineering and calculational details, the reader is referred to the excellent texts by Green and Willhite as well as Lake that are listed in the bibliography.

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Biographical Sketch

Tony Kovscek is an Associate Professor of Energy Resources Engineering at Stanford U. His academic interests center around the physics of heat and fluid transport in porous media as well as the efficient use of energy. In collaboration with his research group, he examines the physics of transport in porous media at length scales that vary from the pore to the laboratory to the reservoir. The organizing themes are flow imaging and image analysis to delineate the mechanisms of multiphase flow (oil, water, and gas) in porous media and the synthesis of models from experimental, theoretical, and field data. In all work, physical observations, obtained mainly from laboratory and field measurements, are interwoven with theory. Kovscek holds B.S. and Ph.D. degrees from the U. of Washington and U. of California at Berkeley, respectively. In 2006, he was awarded the Distinguished Achievement Award for Faculty from the Society of Petroleum Engineers.