

Optimization of Hydrocarbon Recovery

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One of the most significant long-term trends affecting the future vitality of the petroleum industry is the public's concerns about the environment. Recognizing this trend, API member companies have developed a positive, forward looking strategy called STEP: Strategies for Today's Environmental Partnership. This program aims to address public concerns by improving industry's environmental, health and safety performance; documenting performance improvements; and communicating them to the public. The foundation of STEP is the API Environmental Mission and Guiding Environmental Principles. API standards, by promoting the use of sound engineering and operational practices, are an important means of implementing API's STEP program.

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- To advise promptly appropriate officials, employees, customers and the public of information on significant industry-related safety, health and environmental hazards, and to recommend protective measures.
- To counsel customers, transporters and others in the safe use, transportation and disposal of our raw materials, products and waste materials.
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- To commit to reduce overall emissions and waste generation.
- To work with others to resolve problems created by handling and disposal of hazardous substances from our operations.
- To participate with government and others in creating responsible laws, regulations and standards to safeguard the community, workplace and environment.
- To promote these principles and practices by sharing experiences and offering assistance to others who produce, handle, use, transport or dispose of similar raw materials, petroleum products and wastes.



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Manufacturing, Distribution and Marketing Department

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Optimization of Hydrocarbon Recovery

SECTION 1—INTRODUCTION

The concept of recovery optimization is, in its broadest sense, to achieve an environmentally sound site closure in the appropriate time frame for the least cost (That is, to maximize efficiency of the selected system). Optimization can be applied at various levels and is a function of the goals and the evaluation criteria against which a system's effectiveness is measured. For example, optimization could be applied to a recovery system using the concept of maximizing light non-aqueous phase liquid (LNAPL) recovery as the goal. At the lowest level, optimization could be applied to the design and operation of a single well. At the highest level, optimization would be applied to the design and operation of an entire remediation system. There is essentially a continuum of remedial choices ranging from

containment to implementation of the most complex recovery systems, all of which can be optimized to enhance efficiency and lower costs. In general, remediation optimization should consider this continuum of technologies required to achieve appropriate cleanup target levels for the site. Typical technologies may consist of pump and treat for plume control and hydrocarbon recovery, followed by soil venting for removal of residual hydrocarbons in the vadose zone. The advantages and disadvantages of various remedial systems have been discussed in detail in API Publication 1628 Section 7.0 [1]. This document will focus on site-wide recovery system optimization, as system designs and operation and maintenance (O&M) are covered in separate documents.

SECTION 2—LNAPL MIGRATION

Understanding the migration of LNAPL in the subsurface is important to all of the remedial technologies and their subsequent optimization. Thus, a brief review of the mechanics of this migration will be presented. When a release of a petroleum product that is less dense than water, LNAPL, occurs in the subsurface, it can be distributed in the subsurface in several phases. Some of the LNAPL will adhere to the soil particles and become trapped in the small pore spaces, becoming immobile; this is called *residual LNAPL* or *residual hydrocarbon*. (Note: In this document, the terms *LNAPL* and *oil* are used interchangeably.) The LNAPL will also volatilize and form a vapor phase, assuming that the hydrocarbon mixture has a volatile component. If a water table is present, as the LNAPL migrates vertically in the pore spaces of the formation, it will encounter pores filled with water. Due to the differences in density and capillary pressures, it will begin to accumulate and a two-phase flow system, consisting of water (the wetting phase) and LNAPL (the non-wetting phase), will develop.

Figure 1 presents a conceptual illustration of the distribution of water, LNAPL, and air in a porous medium, as presented in API Publication 1628, [1]. The continuous pore volume is occupied by water, LNAPL, and/or air and the spaces between represent the porous medium. Several zones are present in the porous medium:

- a. A three-phase zone containing water, LNAPL, and air, where the relative saturations of the three fluids will determine the mobility of each. This section is considered part of the vadose or unsaturated zone.
- b. A two-phase zone, or capillary zone, containing water

and LNAPL, where the relative saturation of these fluids will determine their mobility.

- c. A two-phase zone below the water table, but within the limits of water-table fluctuations, where residual hydrocarbons are present.

- d. A one-phase zone containing only water at some distance below the water table and outside the zone of water-table fluctuations, where only dissolved hydrocarbons are present.

The primary zone of lateral movement of LNAPL near the water table is the two-phase zone (water and LNAPL), where LNAPL saturation can reach a high enough level to become mobile. Figure 2 shows the relative saturation curves for water and LNAPL in this zone and the relationship to LNAPL accumulation in a monitoring well. In general, there is an over-accumulation of LNAPL in the well relative to the formation; this accumulation can be calculated through the saturation-capillary pressure relationships (Chiang and Kemblowski, [2]; Farr, et al., [3]).

This concept of a two-phase system where both water and LNAPL occupy the pore spaces is extremely important in the evaluation of remedial systems and the recovery of LNAPL. The ability of the porous medium to transmit fluids (its permeability) is a function of the relative saturation of the two fluids and is referred to as relative permeability. Relative permeability involves the flow behavior of two immiscible fluids existing in the same porous medium. It means that as the saturation of one fluid decreases relative to the second fluid, its flow capacity will also decrease. Thus, as the saturation of LNAPL decreases relative to water, the