



Land-Based Produced Water Reinjection Treatment

An Online Continuing Education Course for Engineers

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I. Introduction

Produced water is the aqueous liquid phase that is co-produced from a producing well along with the oil and/or gas phases during normal production operations. Usually, the fluids that are removed from the reservoir by the producing well are brought to the surface and separated into an oil stream, a gas stream and a water stream. The main components of the water stream that is separated are:

- Water
- Suspended oil
- Dissolved oil
- Suspended solids (scale, corrosion products, sand, etc.)
- Dissolved solids
- Dissolved Gases (CO₂, H₂S, O₂)
- Bacteriological matter
- Added materials (treating chemicals, kill fluids, acids, etc.)

It should be noted that, over the life of the well or field, the volume of water produced will exceed the volume of oil produced by a factor of 3-6 times. Unfortunately, at the present time, the produced water is not a saleable product of the operation. Hence, an operator is faced with a serious challenge of how to handle relatively large amounts of produced water at the lowest possible cost. In many land-based production operations, the produced water is either injected into a disposal well or the water is injected into a producing formation for enhanced oil recovery purposes via waterflood or steamflood operations. Before being injected for either disposal or enhanced recovery, the produced water must undergo treatment to render the water suitable for use. The purpose of this paper is to present a general, but practical, overview of the equipment and technology involved in water treating for a produced water injection project. This paper is not meant to present an exhaustive coverage of the material but to provide basic, general information with which an operator can become familiar with the primary decisions required to properly treat produced water for injection. To be covered are produced water treating objectives, produced water treating technology and equipment, and a thought process for the practical application of this equipment to land-based injection operations.

II. Produced Water Treating Objectives

Once the decision is made to inject produced water into a subsurface formation for either disposal purposes or for enhanced oil recovery purposes, it then becomes necessary to give consideration to the produced water treating requirements. Produced water treatment is necessary due to the potential negative impacts that produced water may have on the formation.

In general, produced water will have five main categories of “contaminants” from a produced water injection point of view:

- Suspended solids
- Suspended oil
- Scales that form when dissolved solids precipitate
- Bacteriological matter
- Corrosive dissolved gases (CO₂, H₂S, O₂)

Therefore, the objective of the produced water treating system is to remove or reduce these contaminants to a level that makes the produced water suitable for use. Furthermore, the system should be designed to result in the lowest possible capital and operating life-cycle costs.

Suspended solids in produced water may originate from formation fines, scale deposits, corrosion products or bacterial activity. Depending on such factors as size, shape and concentration, particulate matter in the injection water may have a tendency to cause plugging in the formation. In turn, the plugging will result in higher injection pressures and, possibly, lower injection flow rates. Therefore, one of the primary objectives of the produced water treatment system is to remove the suspended solids material to minimize plugging in the formation.

Produced water for injection that is taken from the water outlet of the Production Separator, Oil Treater or other primary oil/water separation device can contain suspended oil (also known as residual oil) in the range of 500 mg/l to 5,000 mg/l or higher. Prior to injection into the formation, the oil content of this water must be reduced for two reasons. First of all, the oil in the injection water may cause damage to the formation. Hence, the oil content of the injection fluid must be reduced to a suitable level for use. Secondly, the oil that is recovered from the produced water is routed to the oil sales meter to generate cash for the operation.

The amount of dissolved solids in the produced water can vary greatly. For instance, the dissolved solids content of produced waters can range from being comparable to fresh water at one end of the spectrum, to being upwards of 300,000 mg/l and higher at the other end of the spectrum. As the concentration of dissolved solids increases, the potential for the dissolved solids to precipitate and form scale deposits in the surface piping and equipment or in the formation also increases. Various types of analyses can be performed to determine the scaling tendency of the injection water. If there is a high scaling tendency, then consideration should be given to injecting scale inhibitor chemicals.

Microbial growth in oil field water systems may be either bacterial or fungal in nature. These micro-organisms are of concern because as they multiply they can cause or enhance corrosion of pipes and vessels, plugging of injection wells, and degradation of chemicals used in enhanced recovery operations. Organisms that thrive in oxygen-containing environments are called aerobes, while those to whom oxygen is detrimental are called anaerobes. An important group of bacteria that can survive in the presence of oxygen but need an anaerobic environment for growth is called facultative anaerobes. Another classification in use relates to the growth habits of the organisms. Those which float freely in the liquid phase are said to be planktonic, while those which prefer to grow attached to a solid surface are said to be sessile. It should be

remembered when evaluating the results of a bacterial monitoring program that many tests depend on detection of planktonic individuals, and that these individuals, even when present in low concentrations, may be indicative of the presence of large colonies of sessile bacteria. It is recommended that operations personnel collect samples and have these tested for bacterial activity. If necessary, chemical biocides can be injected to control the proliferation of these microorganisms.

Produced water from sour formations may contain some amount of dissolved H₂S and/or CO₂. These gases form corrosive acids when dissolved in water. The effects of these gases can be mitigated by removing the gas from solution or by use of corrosion inhibitor chemical additives.

Oxygen is also a corrosive agent when dissolved in water. Although oxygen is not normally a component of produced water when it comes up from the formation, oxygen may leak into the produced water during separation or treating processes at the surface. Therefore, the oxygen content of the water should be monitored and if leaks are found, these should be sealed. Furthermore, equipment or processes that are open to the atmosphere should be avoided so as to minimize the intrusion of oxygen in the produced water. Sometimes it is necessary to commingle a small stream of aerated produced water into the main stream. In these cases, the aerated stream should be treated with an oxygen scavenger chemical prior to mixing with the main stream.

III. Produced Water Treating Technology

The technology for accomplishing these objectives is described below. For each category, several common technologies, from the most basic to the more complex, are given. The proper application of the technology is key to reaching both the performance objectives and the financial objectives of a particular project.

Suspended Solids Removal

As explained earlier, suspended solids have a tendency to plug the injection formation thereby tending to cause the produced water injection pressure to increase and the produced water injection flow rate to decrease. In order to predict the nature and extent of any problems that may arise due to contamination of the produced water by suspended solids, it is advisable to collect samples of the produced water, if possible, to perform a suspended solids analysis. This type of analysis will provide detailed information that is required to properly specify a treatment scheme. The suspended solids analysis will report on such issues as the density of the solids, the concentration of solids in the water stream, the size distribution of the solids and the type of solids. Having this information helps operating personnel better understand the problem that needs to be solved.

Suspended solids that are present in the water will exist as distinct particles of varying sizes and densities dispersed throughout the water phase. Particles that are heavier than water will tend to drop to the bottom of the pipe, vessel or other type of container at various rates. There may also be very small particles or oil-coated particles that are neutrally buoyant such that they tend to remain in the water phase. Stoke's Law describes the vertical velocity at which a particle falls through a liquid phase. Stoke's Law can be related by the following equation:

$$v = \frac{g \Delta\rho(d_p)^2}{g_c 18\mu_L}$$

where:

$\Delta\rho$ = difference in density of the dispersed particle and the continuous phase,

g = “g-force” acceleration factor,

g_c = gravity acceleration constant,

d_p = dispersed particle diameter, and

μ_L = viscosity of the continuous phase.

The information obtained from the solids analysis is used along with the Stoke’s Law equation to properly evaluate and select a solids removal system.

A primary objective in the design and engineering of water treating equipment for solids removal is to maximize the vertical velocity or settling velocity of a solid particle. In other words, the higher the settling velocity, the easier it is to remove the solids from the produced water stream. Based on the Stoke’s Law equation above, it is clear that the settling velocity can be increased by:

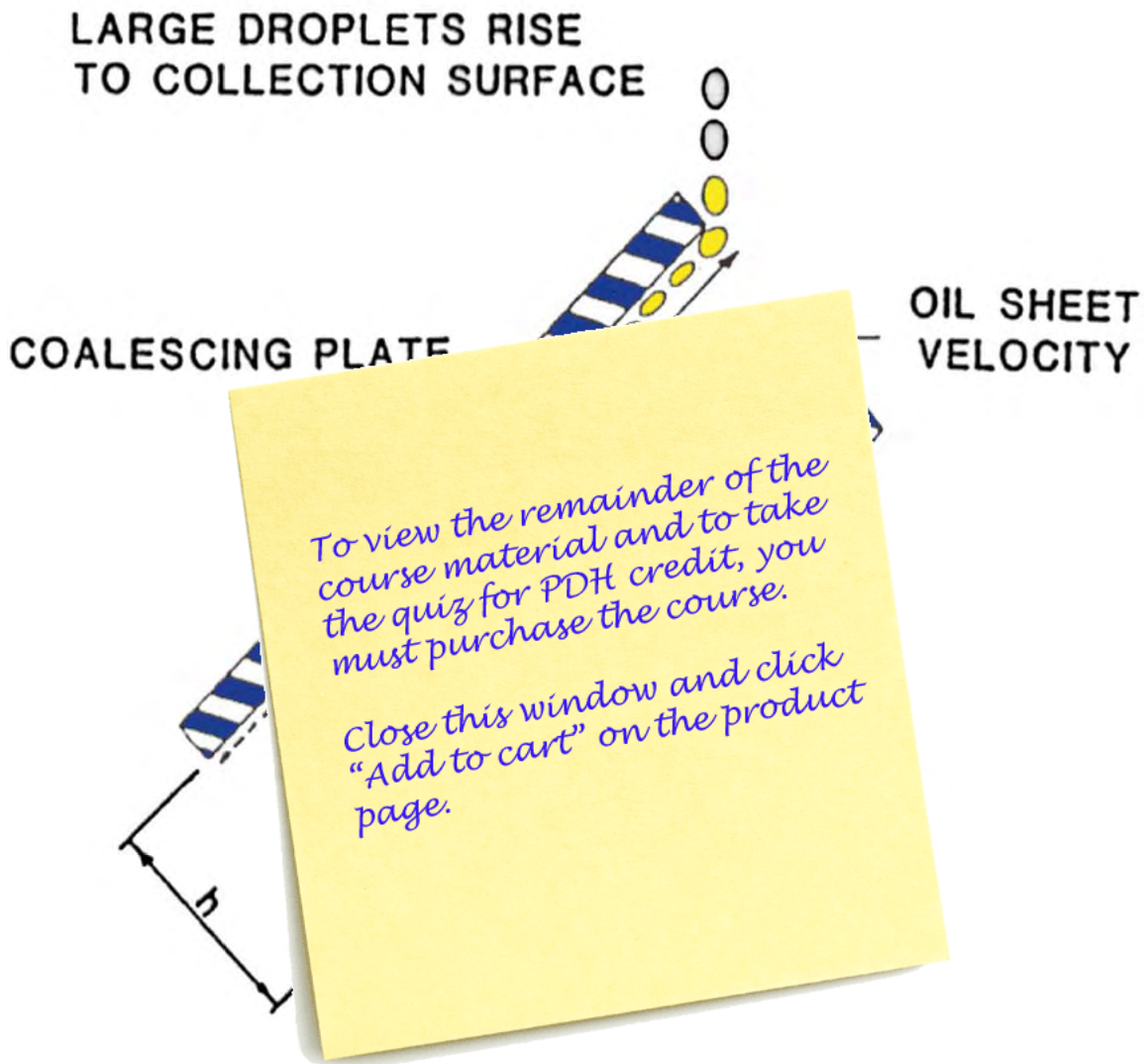
1. Increasing the size of the solid particles (i.e. by using chemical agents), or
2. Increasing the difference in density between the oil droplet and the water phase, or
3. Lowering viscosity of the water (i.e. by operating at the highest possible temperature),
or
4. Increasing the “g-force” imposed on the fluid (i.e. by centrifugal motion)

Solids removal is usually done in stages from primary bulk removal to final polishing. The number of stages required is a function of the type of solids in the stream, the size distribution of the solids, the concentration of the solids and the level of removal required for the application.

As already stated, large and relatively dense particles will be easiest to remove. The separation of relatively large, high-density solids can be accomplished by simply allowing enough time for the solids to settle by gravity to the bottom of a tank or vessel. This is termed gravitational settling. This is the most simple and least costly solution to solids removal. Gravitational settling can be accomplished by using settling tanks or skimmer tanks. These types of tanks are commonly installed at land-based operational facilities due to the fact that space and weight constraints are not very stringent and the installed cost is relatively low.

The speed of solids removal via gravitational settling can be greatly enhanced by use of inclined parallel plates (See Figure 1).

Figure 1. Parallel Plates



A section of closely spaced, inclined parallel plates can be placed in a rectangular tank or in a cylindrical vessel through which a produced water stream containing suspended solids flows. Equipment designed on this principle is termed a parallel plate interceptor (PPI) or a corrugated plate interceptor (CPI). The plate pack accomplishes two things: 1) it shortens the distance that a solid particle must travel before it reaches a settling surface; and 2) it provides plenty of surface area for solids to settle out of the water stream. Hence, not only is the settling process faster but the equipment required is smaller and lighter. However, the capital cost of the equipment may be more than a simple skim tank. See Figure 2.