Issues Related to Oil/Water/Solids Separation at a Commercial Produced Water Treatment Facility Operating in South Central Wyoming

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ABSTRACT

Since 1999, Crystal Solutions (CS) has been treating natural gas produced water using a freeze-thaw/evaporation (FTE®) facility located in south central Wyoming. Oil/water/solids separation is an important step in the operation of the facility. This is accomplished using conventional oil/water/solids separation equipment in the system design. Produced water unloaded from trucks flows into and through two 400 bbl vertical tanks connected in series. These tanks are each equipped with fire tubes fueled with propane and controlled to a selected temperature set point. Inlet and outlet piping enter and exit the top of the tanks and extend vertically to the middle of the tanks. Oil collected in the upper portion of each tank is manually fed to a 300 bbl condensate storage tank by gravity. Water from the second 400 bbl tank flows into a lined separation pond one-quarter acre in size. This pond, equipped with duck netting, provides additional residence time to insure complete separation is achieved. Water is pumped from the lower portion of the separation pond to one of the eight facility treatment ponds. Oil collecting on the top of the separation pond is recycled into the first 400 bbl separation tank as required.

The operational history of the separation system is discussed along with economic issues related to the system operation. In addition, recommendations for design modifications to future systems are provided.

INTRODUCTION

BC Technologies, Ltd. (BCT) and Crystal Solutions, LLC (CS) have been using the freeze-thaw/evaporation (FTE®) process to treat oil and natural gas produced water in Wyoming's Greater Green River basin for the past five years. Oil/Water/Solids (OWS) separation is a critical unit operation in this, as well as most, produced water treatment and/or disposal processes. A conventional OWS separation system is currently in use at the CS FTE® produced water treatment plant located south of Wamsutter, WY. In this paper, observations regarding the operation of this conventional OWS separation system are provided with the hope that research to improve the efficiency and ease of operation of these systems will be stimulated.

Pretreatment of produced water to efficiently and effectively separate the oil, water and solids contained in produced water is not only important to the success and efficiency of the treatment operations employed downstream, it is also important for economic, environmental and national security reasons. Oil recovered in the pretreatment of produced water can be a significant by-product of the treatment operation. In fact, over 1% of the produced water delivered to the CS facility is recovered and sold as oil. The sale of this oil provides economic benefit to the operation. From an environmental standpoint, the efficient recovery of this oil is necessary to both protect migratory birds and reduce the emissions of volatile organic compounds to the atmosphere. Further, optimizing the recovery of domestic energy resources is a national security issue. In summary, the USA must be concerned with recovering as much of its domestic energy resources as possible. Effective OWS separation must become an industrial standard whether accomplished by minor modifications to improve conventional operations or by utilizing better technology.

In addition, there are many intangible benefits to effective and efficient OWS in produced water management. Oily water is undesirable for produced water handlers, energy producers and those not familiar with energy production. The volatile and semi-volatile organics contained in oily water have strong odors when released to the atmosphere. Further, anaerobic biological reactions of the oil produce additional unpleasant odors. Elimination of oil in produced water would make the jobs of produced water handlers and energy production personnel much more pleasant and generate far less public concern over energy development.

BACKGROUND

During oil and gas production water is produced at the wellhead; this water exists naturally in the underground oil and gas producing zones. The water and other condensable liquids are removed at the wellhead; additionally the produced water is separated from the oil and/or natural gas condensate. Thus, oil and condensate collected by OWS separator systems at produced water treatment plants is the result of ineffective wellhead equipment operations.

The OWS separation process must also separate emulsions and paraffin that often collect at the oil water interface in the separation systems. Conventional OWS separation systems focus on the collection of condensate and oil, separation of solids and the discharge of water. Due to the nature of the produced water some of the solids become coated in oil and grease, ending up as suspended colloidal solids. Suspended colloidal solids are solid particles that are held in solution by a charge; these colloidal solids are difficult to separate from the condensate. Solids that settle on their own are another issue entirely. The solids that the OWS system must separate range from fine particles such as drilling mud and sand to large objects such as wrenches and gaskets. In field applications, OWS separators must be designed to handle a broad range of materials.

CONVENTIONAL DESIGNS

Conventional OWS separation systems are driven by gravity separation. A difference in density between the fluids and solids is the driving force for this type of separation. Gravity separation can be modeled by Stoke's Law, which states that a particles rise rate is dependent on the surrounding fluids viscosity, the difference in density between the particle and its surrounding fluid, and the particles size. For OWS applications, the Stoke's Law equation can be expressed as:

$$V_t = (g/18m)*(r_w-r_p)*D^2$$

Where:

- V_t is the rise rate of the oil droplet
- r_w is the water density
- r_p is the particle's density
- D is the droplet diameter
- g is gravity and
- m is the viscosity of the water

Another important design factor is the OWS separation systems minimum horizontal area, which can be expressed as:

$$A_h = F*(Q_m*100)/V_t$$

Where:

- A_h is the minimum required surface area of the separation system
- F is a correlated turbulence and short circuiting factor
- Q_m is the water flow rate through the system
- V_t is the oil rise rate

These design equations can be used to show that systems with longer residence times will achieve better separation and removal. This increased separation is due largely to the fact that particles with slower rise rates, due to smaller density differences and smaller droplet diameter, will rise to the oily layer. Residence time is an important design consideration because it can vary substantially when operating produced water treatment facilities. Remembering Stoke's law, the rise rate is dependent on the densities of the oil and wastewater, viscosity of the wastewater and diameter of the oil droplet. The design of a specific OWS system is further complicated by the density, or specific gravity, of the condensate, which is largely dependent on the field where it is being produced. For produced water handling systems located where water is collected and delivered by truck, the diameters of the oil droplets will be much smaller due to turbulence from offloading. Due to the large number of design considerations, many producers choose to use a standard OWS system design.

The American Petroleum Institute published the standards for OWS system design and operational criteria. (API 1990) The separation system that the API designed is referred to as a Coalescing Gravity Separator (CGS); Figure 1 illustrates a basic system.

An API OWS separation system forces water to flow through a series of baffles. When properly designed, petroleum is collected between the baffles and removed. Solids are collected on the bottom of the tank. Recently, the baffles in these systems have been replaced with coalescing media. OWS separation systems that utilize coalescing media are referred to as coalescing plate interceptors (CPI). Figure 2 illustrates a common CPI system.

In a standard CPI system the oily produced water enters from the lower right port in Figure 2. As the oily water flows through the system it contacts oleophilic ("oil attracting") plates. The plates attract the oil to their surface, causing larger droplets to form. As illustrated by Stoke's Law, the droplet rise rate is a function of the droplets diameter squared. The increase in droplet diameter causes the oil to rise to the surface much faster. Oil free water is collected from the left port while condensate is collected off of the top of the system. The increased oil rise rate allows the systems to be much smaller and still maintain a high efficiency of oil recovery. However, the significant amount of grease and solids in produced water decrease the effect of the coalescing media. Both API and CPI separators may be used with other equipment to enhance separation.

Another common OWS separator design is a fire tube system. Fire tubes increase the temperature of fluid in a tank by burning natural gas or propane to heat air, which is forced through a heat exchanger inside the tank. Theoretically, heating the produced water decreases the viscosity. Again, Stoke's Law shows us that decreasing viscosity causes the rise rate to increase. Oil water separation can also be enhanced at the wellhead by adding equipment for OWS separation such as gun barrels. Gun barrel systems also rely on gravity separation, and can be referenced on the Oklahoma Marginal Wells Commission's online *Lease Pumpers Handbook*. (MWC)

CS's OWS Separation System Design

The design of the OWS separation system at the CS FTE® produced water treatment plant near Wamsutter, WY was typical for the location. The plant is located in a major natural gas field and the design is similar to the practices in the area. Water is trucked to the facility and unloaded into a tank battery consisting of two separation tanks in series. The tanks achieve a primary separation, and water flows into a lined separation pond where a secondary separation is achieved. Residual condensate that is collected in the pond is recycled through separation tanks. Condensate is transferred from the separation tanks to a condensate storage tank when the condensate is of a salable quality.

Earthen berms around the tank battery for spill containment, as well as a truck unloading spill containment zone, are also included in the design. Spill containment in the truck unloading area includes a synthetic containment zone liner and a spill collection and retrieval system to prevent the spread of contamination in case of a catastrophic event. Trucks unload into the tank battery through a 4-inch diameter steel pipeline. The trucks connect to the pipeline through a globe valve using a 4-inch hose. This system allows the truck drivers to quickly drive up, connect, unload and leave. After truck unloading, the produced water flows through a series of separator tanks.

The separation tank (ST) system (Figures 3 and 4) consists of two 400 bbl steel tanks, which are 20 feet tall. The ST system is equipped with pressure relief, piping ports and fire tubes. The fire tube systems use 8-inch diameter fire tubes, and 6-inch stacks. The two separation tanks are connected in series by 8-inch steel piping. Although the tanks are configured in series, condensate is collected from each tank. Transfer of the condensate occurs through piping attached to ports located 4.3 feet below the pop-off lid on ST1 and 4.7 feet below the pop-off lid on ST2. The port is vertically lower on ST2 than ST1, which assists with gravity transfer of condensate to the condensate tank (CT). Separated water is automatically transferred to the separation ponds as trucks unload produced water.

The separation pond (SP) system consists of two ponds; SP1 has a volume of 5,000 barrels, while SP2 has a volume of 1,000 barrels. SP2 is installed as a spare in the event that SP1 is taken out of service for repair or maintenance. Both ponds are constructed with clay liners covered by a leak detection system and HDPE lining. Both ponds are also equipped with duck netting. Water is transferred from the bottom of the pond to the treatment system. Condensate that collects in the ponds is recycled back to the ST system for collection. From the ST system, condensate is transferred to the Condensate Tank (CT).

The CT (Figures 3 and 4) is a 300 bbl steel tank that is 15 feet tall and is used for condensate storage. The CT is attached to both separation tanks by a 2-inch diameter pipeline. The condensate flows into a port that is 1 foot below the pop-off lid on the condensate tank.

Reasons for the system design were that the tank farm reduced the amount of land required for separation and cost less to construct. Tanks are prefabricated, inexpensive, and hold up well in our operational environment. The smaller cross-sectional area of the tanks as opposed to the ponds allow a thicker layer of oil to accumulate, thus allowing for easier transfer and more efficient separation. Tanks also reduce the amount of volatile organics loss. One of the main purposes of the system is to recover oil from the system instead of releasing it back to the environment.

Operation of the CS OWS Separation System

Plant operators are required to take daily tank level measurements and record them. The operator is required to take level readings of the oil surface and the oil/water interface for both the separation tanks and the condensate tanks. This is accomplished by using an oil water interface probe. Tank level measurements must be taken early in the morning prior to arrival of water trucks. Since trucks regularly arrive as early as 7:00 AM, operators must leave themselves enough time to transfer condensate before any trucks offload. It is critical that the transfers be made before the trucks offload into the separation tanks. Offloading causes the oil and water to blend, and may require several hours for stabilization of the oil/water interface to allow for accurate readings. The system also requires significant amounts of time for sediment introduced during truck offloading to settle through the condensate layer.

After taking level measurements, operators sample ("thief") the tanks if sufficient condensate levels exist for transfer. "Thief" samples are taken from one foot below the vertical distance of the manual transfer ports. These samples are analyzed for Sediment and Water Percentages (S+W%). If the S+W% is low enough to meet standards required for sale, 0.05% or less, the condensate can be transferred to the CT. Generally, ST2 is the tank containing sufficient quantities of condensate to test for transfer. On rare occasions ST1 has contained enough oil of a high enough quality to transfer to the CT. This normally occurs if the most recent water delivery contained a large volume of condensate.

In addition, the bottom of the tank is periodically sampled using the "thief". This sample is taken to check the amount of tank bottoms that exist. Sampling ensures that the condensate will achieve a quality suitable for sale. Operators are also required to unload the CT when the tank is full of condensate that is suitable for sale. This task is accomplished by transferring through a 4-inch hose that is attached to a valve located one foot above the bottom of the CT. Operators are also occasionally required to transfer the oily layer from the separation pond back to the ST system through a bag filter to remove suspended solids, and to transfer tank bottoms to the separation pond when accumulation is large.

TOTAL PRODUCED WATER THROUGHPUT AND OIL COLLECTED

Since the CS FTE® produced water treatment plant has been in operation, collected condensate volumes have amounted to roughly one to two percent of the total produced water throughput. The total volume of condensate collected depends greatly on its specific gravity and the field where the water is being produced. Condensate produced in the Greater Green River Basin generally has a low specific gravity and a correspondingly high API gravity. The volume of condensate arriving from a well is largely dependent on external factors such as the well design, well operations (production, drilling, work over and stimulation), and the design and operation of the wellhead OWS separation system. The total volume collected at the CS plant is indicative of the effort put forth by the plant operators to keep the oil out of the FTE® treatment system.

ECONOMIC ISSUES

Issues associated with the CS OWS system include the fact that it would be a much larger benefit to the oil and gas producers to recover their own oil at the wellhead. OWS separation at a produced water handling facility is carried out to keep the oil out of the treatment facility. Maintenance and operating expenses for this system include the cost of propane for the fire tubes, recycling of fluids through the system, cleaning, testing and taking level measurements. Sales of condensate can be used to offset these costs.

PROBLEMS ENCOUNTERED

The CS OWS system encounters significantly fewer problems during the summer. One of the main problems experienced with this system is the freeze up of valves on the transfer line. Another problem occurs with draining the transfer lines on the tanks. If the transfer lines are not drained then freeze-ups also occur. Sometimes if the weather is cold enough the condensate line will freeze up while the transfer is finishing.

Two other operational issues related to the operation of the OWS separation system are that it smells bad and is messy to work with. Also transfers of water from the separation ponds to the treatment system can transfer oil if not carefully supervised. When oil is transferred to a facility treatment pond, the operator responsible for the transfer is required to immediately skim the oil off of the pond using a vacuum tank. After collection, the oil is recycled back through the ST system.

There are also operational issues arising from the delivery of produced water to the facility. The CS ST system is designed with pressure relief valves. During water delivery, air can be pushed through the separation tanks if the offloading process is not carefully monitored. The air introduced into the separator tank results in produced water and/or oil being forced out of the tank through the pressure relief valve. Plant operators are required to immediately wash the tank when this occurs. Turbulence is another problem caused by unloading trucks. Turbulence causes the oil droplets to split apart and causes the separation to take longer to achieve. The increased separation time leaves the operator a very small window for testing and transferring condensate.

RECOMMENDATIONS

Operational experiences have led to the conclusions that the use of fiberglass separation tanks with two cleanout ports would be preferable to the standard tank design. The second cleanout port would allow for tank cleaning without removal of the fire tubes. It may also be practical to use a cone-shaped bottom on your condensate tank to facilitate the removal of the tank bottoms after sales of condensate.

Conventional OWS separation systems are effective if carefully operated and diligently maintained. Improved OWS separation at the wellhead is needed along with improved OWS separation at treatment and disposal facilities. Research should be conducted to improve OWS separation system designs so that they are more effective and require less attention from operators. Improvements in OWS separation system design will result in increased recovery of domestic oil reserves, improved production economics, reduced odors and reduced atmospheric emissions from production.

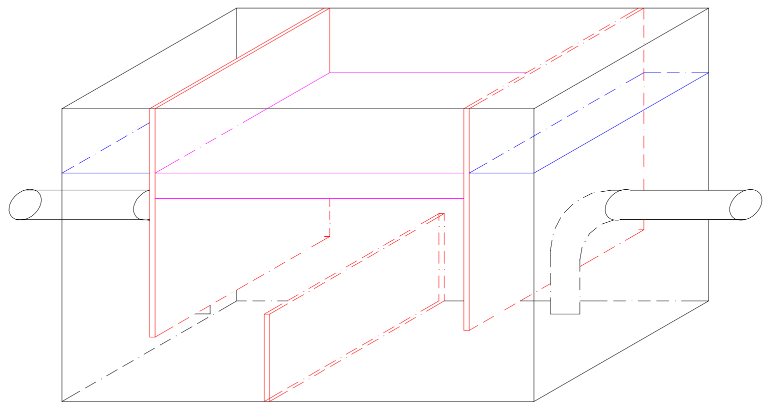

Figure 1. A standard API system.

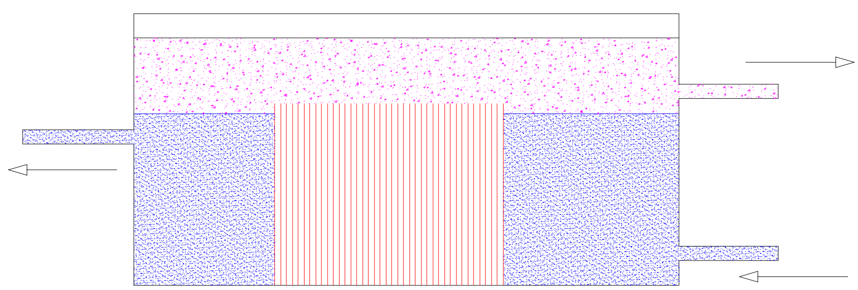

Figure 2. A standard CPI system (Cross sectional view).

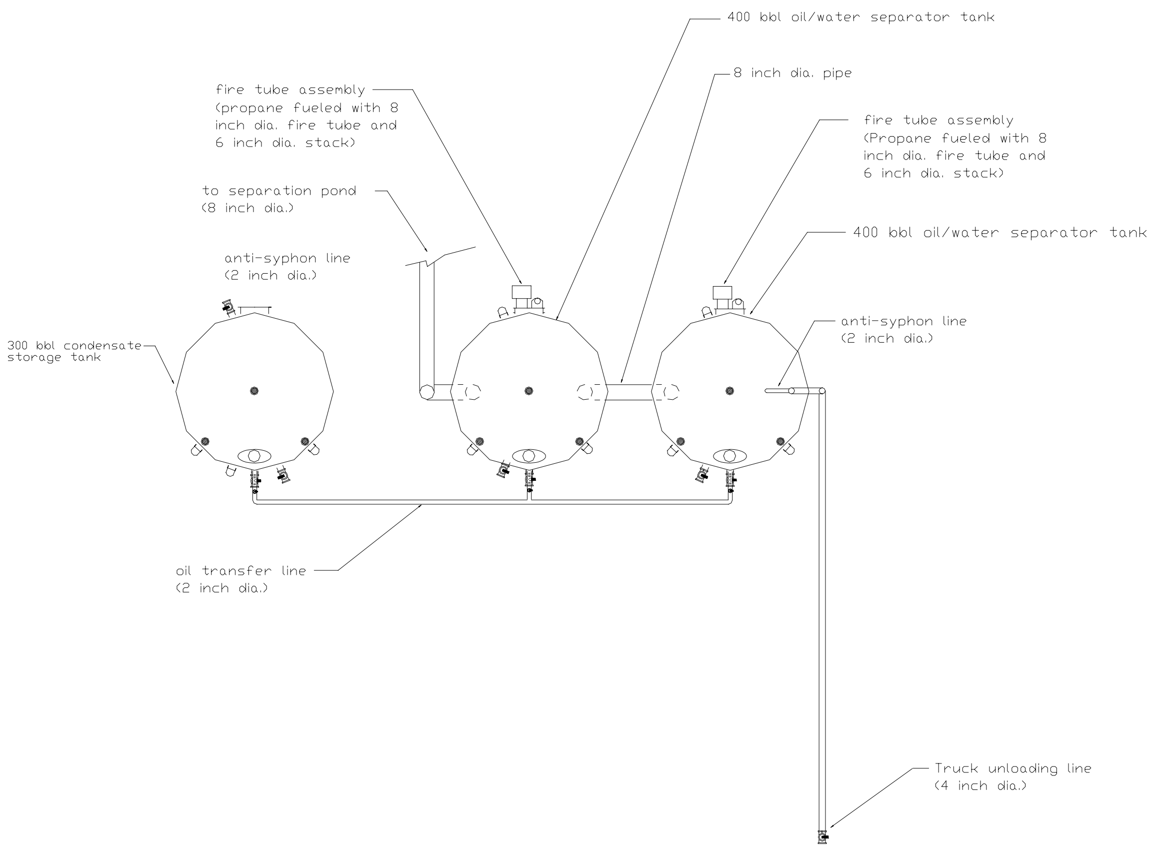

Figure 3. The CS OWS Tank Battery (Top View).

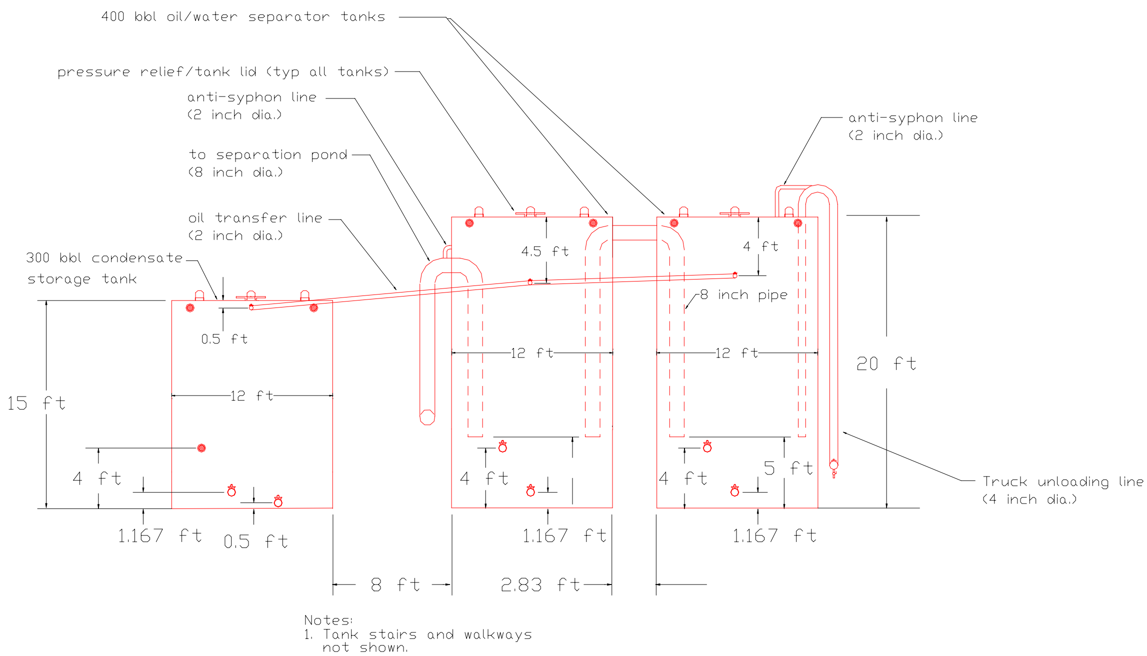

Figure 4. The CS OWS Tank Battery (Side View).

REFERENCES CITED

1. "Design and Operation of Oil/Water Separators", American Petroleum Institute (API) Publication, 421 (1990).

2. The Lease Pumpers Handbook. Oklahoma Marginal Wells Commission (MWC), Internet Website, www.marginalwells.com, , Oklahoma City, Oklahoma.