

## Oil Recovery from Production Waste Reduces Environmental Impact

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### Abstract

Production facility waste is typically a complex and stable water-in-oil emulsion produced during well tests and initial production. This waste can also be comprised of production rejects and tank bottoms. The oil phase can contain a complex mixture of hydrocarbons, including waxes and asphaltenes, which may be solid or semi-solid at ambient temperature. Often, the production waste is stored in open pits for considerable lengths of time and the overall composition changes due to evaporation of the lighter hydrocarbons, rain water addition, and sunlight cross-linking the hydrocarbon molecules.

High oil prices offer significant incentives to recover and re-use the valuable oil component of this waste stream. Both environmental and business objectives can be met by treatment of production waste and decreasing the waste volume, ultimately leading to pit closure and land restoration.

A customized solution using the modular approach to equipment design in combination with unique chemical packages is needed to ensure treatment success. This paper describes the techniques used to identify and design chemical packages and how this process is linked to equipment selection. Treatment modules are described which liquefy the waste steam and enable effective chemical treatment and phase separation. The separated, clean oil is of such quality that it can be returned directly to the refinery or the crude export stream. The benefits and success of this process are demonstrated using specific examples of production waste treatment.

### Introduction

In almost every instance of oil-well production, crude oil is produced in the form of a water-in oil emulsion, with the water arising from the formation, injection procedures and other activities. Surface separation equipment incorporated in the production facilities dehydrates the majority of the crude, but a fraction of highly stable emulsion becomes production waste. The emulsion is often combined with oily waste streams from other sources such as tank residues, separator sludges, dehydration and sweetening unit wastes, coalescer interfaces, pipeline pigging, vessel blow-downs, well testing and workover fluids, and production rejects.<sup>1</sup> Solids such as produced sand and contaminated soils may also be present as well as heavy metal scales (such as calcium carbonate,

calcium sulfate, barium sulfate) and corrosion products.<sup>1</sup> The waste is often stored in large outdoor pits which stratify over time. Heavier solids settle to the bottom of the pit. The water-in-oil emulsion and any lightly contaminated oil form the upper layers of the pit and in some cases non-emulsified water will form a discrete water layer.

Classification of the waste is dependent on the regulatory framework of the country in which the waste is sited. For example, Indonesia classifies oily sludges as hazardous and toxic wastes while in the U.S. they are exempt from hazardous waste regulations under the Resource Conservation and Recovery Act (RCRA).<sup>1</sup> Proper management of such wastes is important for the protection of human health and the environment. If storage pits are not adequately constructed or maintained, contamination of the surrounding environment and ground water is a concern. Perforations in both production waste pit liners and above-ground storage containers, especially in the instances of decades-long holding periods, can result in seepage of the contents into the ground. Water, soil and air may provide pathways by which potentially polluting materials can migrate from their original source and contaminate the environment, including groundwater and nearby waterways.<sup>1,2</sup> The waste may trigger processes that have adverse effects on the ecosystems of the area and affect the health of the animal and human populations within the immediate vicinity.<sup>2</sup>

Environmental legislation therefore drives remediation of the production waste pits. Previous disposal methods ranged from open burning and land spreading to sophisticated techniques such as slurry fracture injection.<sup>2</sup> These techniques do not allow for oil recovery, and in the case of burning, posed environmental or regulatory problems in themselves.<sup>2</sup> As the price of crude reaches unprecedented levels, remediation techniques which allow for recovery of the oil fraction in these pits allows remediation to be commercially attractive.

By use of the chemical and equipment selection techniques discussed in this paper, a large proportion of the production waste can be treated and the oil recovered and recycled back into the production facility. The treatment operation can be self funding or even profit making. Treatment is technically challenging due to the stable emulsions present which can vary widely in composition and characteristics. A customized treatment solution should be designed and executed for each discreet case. A key to optimal design and ultimate project

success is the use of accurate sampling methods and comprehensive analysis techniques. Consideration must also be made for country and regional environmental regulations, the customer's specifications for final separated products, and health and safety performances.

In cases where pit closure is required, the solids layer at the base of the pits and any contaminated soil must also be treated. Several treatment options are available including land spreading/ land farming, composting, stabilization, thermal processes, downhole injection and off-site disposal.<sup>1,3,4</sup> Choice of suitable remediation or treatment technologies are site and location specific and also depends on the nature and quantity of the material to be processed.

This paper presents techniques to characterize production waste samples and define unique chemical packages to treat and separate the waste. The separation characteristics link to equipment selection and operation of full-scale treatment plants to enable hydrocarbon recovery of high enough quality to return to the production plant or crude export stream. Examples of treatment modules for this application are described and the benefits and success of integrating chemical and equipment selection demonstrated for production waste management.

### **Characterization of Production Wastes**

Before the design of any oil-recovery equipment can commence, or any treatment regime proposed, the physical and chemical characteristics of the waste material must be known. This requires the collection and analysis of representative samples from the waste pit. Often these waste mixtures are so viscous that their homogeneity cannot be guaranteed and a matrix of samples is collected at various points and depths in the waste pit.

Several techniques are used to determine the physical and chemical characteristics of these waste samples. Knowledge of these will determine the most appropriate chemical and physical treatments to recover the hydrocarbon phase.

### **Continuous-Phase Characterization**

For the purposes of this paper the waste layers which comprise water-in-oil and complex emulsions are considered. The hydrocarbon continuous phase can include paraffinic, naphthenic, aromatic, or other complex molecules; "waxy hydrocarbon" describes an alkane with a carbon chain length of 18 and greater. In some countries, production wastes pits have existed for 30 years or longer, giving ample time for weathering effects such as evaporation of the light-end fractions, oxidation and cross-linking, leaving behind waxy residues which are solid or semi-solid at ambient temperatures which further entrain solids and encapsulate water droplets.

The organic continuous phase can be analyzed by Gas Chromatography-Mass Spectrometry (GC-MS) and Fourier Transform Infra-Red (FTIR) methods to provide information on the chemical nature of the hydrocarbons, including the carbon-chain length and the presence of aromatic compounds, organic acids and bases.

### **Flash-Point Measurement**

The flash point is the minimum temperature at which there is sufficient evaporated fuel in the surrounding air to initiate combustion. As temperatures increase, vapor pressure increases and the concentration of evaporated flammable vapor increases. Because production wastes will most typically be heated as part of the oil recovery process to melt the waxy and semi-solid hydrocarbons, it is important to know the flash point of the mixture so that adequate safety measures can be included in the process design. A typical measuring device to determine the flash point is the Pensky-Martens Closed Cup.<sup>5</sup> The apparatus consists of a small cup containing the sample which is gradually heated toward its flash point while stirring. At regular intervals an open flame is directed into the cup. At the flash point, it will ignite the contents of the cup and the temperature at which this occurs is recorded.

### **Oil, Water and Solids Content**

The oil, water and solids content of a sample will determine the quantity of each phase to be separated by both the chemical and mechanical separation and will also allow estimation of potential oil recovery rates and volumes. An excellent method for determining the fraction of each phase is the oilfield retort distillation apparatus.<sup>6</sup> Temperatures at or above 510°C (950°F) volatilize liquids which re-condense into a measuring cylinder. Water collects below the organic layer and volumes of both water and organics can be determined. Solids remain in the test cell and can be calculated by either weight or volume balance with the recovered material. Often a sample that is solid at room temperature will be shown by the retort method to contain mostly waxy hydrocarbons that melt at the high temperatures and appear as recovered oil.

Another method for determining the sample composition is the use of a heated laboratory centrifuge. This method is used to simulate typical phase separation that could be achieved at temperatures applied during large-scale treatment. The heated laboratory centrifuge is used to evaluate the ability of the production waste to phase separate with and without chemical addition and is also used to determine the volume and strength of any emulsion which will collect at the oil/water interface. Heating to 85°C (185°F) is typically required and the centrifuge is spun at 1800 relative centrifugal force (RCF). The reduction in oil viscosity from melting of the wax liberates the water droplets and encapsulated solids; the applied gravitational forces allow the solids and water to collect beneath the organic layer where volumes can be measured and recorded.

### **Viscosity**

Viscosity measurement over a range of temperatures is required to determine the engineering parameters for full-scale equipment design, such as size and power of transport pumps, heat requirements and hence sizing of any boilers or other equipment used to heat the material before treatment. It is beneficial to heat the material and decrease the viscosity to aid pumping, enable mixing and dispersion of chemicals and to increase the efficiency of phase separation. Rotational

viscometers, common in the drilling fluid industry,<sup>6</sup> are appropriate instruments for determining this property provided that a means of heating the sample and measuring its temperature are available. In some cases, the viscosity of a sample will be too great for most pumps to handle, even at elevated temperatures, and other material transport devices will have to be identified.

### **Emulsion Characterization**

The water-in-oil emulsions can be stabilized by naturally occurring emulsifiers that create a rigid interfacial film around the water droplets and form a barrier to water coalescence. For example, production waste in Indonesia was identified as containing acyclic metal carboxylate soaps formed by reaction of long chain fatty acids in oil with sodium bicarbonate-rich waters.<sup>7</sup> Other metal soap sludges have also been described based on calcium soap emulsions.<sup>7</sup> If fatty acids are present, atomic absorption spectroscopy may be able to identify the presence of sodium or calcium salts of these acids.

### **Analysis of Solids**

Solids present in production wastes can include clays and weighting minerals from drilling fluids, sands, inorganic salts, metal shavings, soils, asphaltenes, wax crystals, products of corrosion, and mineral scales. Finely divided particles can suspend at the oil-water interface and form rigid structures that enhance the stability of the emulsion.

Analysis by X-ray diffraction (XRD) identifies inorganic solid species. A battery of solubility tests may be used to characterize the organic solids. Asphaltenes are polycyclic, high-molecular-weight organic solids with carbon-chain length of 30 or more. They are insoluble in n-heptane or pentanes but soluble in toluene, methylene chloride and chloroform and can be dispersed by acids. Resins present in crude oils, which are polycyclic also contain significant aliphatic side chains and are soluble in n-heptane and pentanes but insoluble in ethyl acetate. Wax crystals are insoluble in acetone and methylene chloride but soluble in xylene, toluene, limonene and naphtha.

Particle-size distribution of the solids fraction is also an important characteristic to be determined. As finer particles have higher surface area per unit volume than coarse particles, higher dosages of solids-specific treatment chemicals may be required. The particle size and nature of the solids will also enable selection of efficient solids-separation equipment.

### **Development of Treatment Packages**

Identification of an appropriate production waste treatment process takes place on a laboratory scale using a series of treatment trials on representative samples of the waste material. The sample may be either a blend of volumes taken from a matrix of locations distributed throughout the geometry of the production waste pit or a volume intended to represent a worst-case treatment scenario. Although there will be significant sample variability, even from the same source, it is generally the case that identification of a basic chemical package is possible which will be appropriate to treat for the

majority of the material. Adjustment of dose or addition of alternative products to the package may be required to accommodate batch variations.

Gravity separation without the addition of treatment chemicals over a range of temperatures is examined in simple bottle tests, where samples are placed in water baths and the separation into solids, water and oil layers is observed over time. Separation of the oil phase from the emulsion in high percent recoveries suggests that the emulsion is relatively weak and may be treated by simply allowing the waste to stand quiescent in a heated container for a set residence time, with the separated phases then recovered.

More often, separation of oil from emulsions will require the assistance of enhanced gravitational forces provided by centrifugation. The heated laboratory centrifuge can be used to determine the amount of heat, RCF and time necessary for emulsion breaking and separation of the oil phase. The centrifuge can be utilized to simulate typical conditions experienced in decanter, tri-canter or disc stack-type centrifuges, relating RCF to the G-force experienced inside the centrifuge bowl. Separation time can be correlated using full-scale treatment flow rates and residence time inside the centrifuge. The exact parameters will be dependent on the type, model and size of both the lab and field centrifuges.

The addition of treatment chemicals is usually the key to enhance phase separation efficiency and rate. If a highly effective chemical treatment package and dosage level is identified, chemicals can also help reduce the amount of heat required for emulsion breaking or even negate the need for centrifugal forces in some cases. It is rare for a single chemical to be the most appropriate treatment for material as complex as production waste. The type of chemical treatment depends, in part, upon some of the constituents identified during characterization of the sample. If waxy long carbon-chain hydrocarbons are present, wax-crystal modifiers, wax-crystal dispersants and pour-point depressants can be part of the treatment package. Asphaltenes require a chemically different set of dispersants and inhibitors. Mineral solids suspended in the mixture are often oil-wet and require a water-wetting agent to enable them to associate with the aqueous phase and subsequently be removed along with the water fraction.

Chemical treatment is pH dependent, and usually a pH of less than 6.5 is needed. Addition of acidic demulsifying formulations during the chemical treatment steps can break metal carboxylate and calcium naphthenate soap emulsions.<sup>7</sup> The acid causes a shift of equilibrium between the metal carboxylate or naphthenate converting it back to free carboxylic or naphthenic acids that are less prone to emulsifying oil.<sup>7</sup> Acidic material also helps disperse the high-molecular-weight asphaltenes into fine particles, which can release droplets of oil or water that had been previously encapsulated by the rigid molecular structure.

Another function of chemical treatment is to destabilize the emulsion, usually by weakening and disrupting the interfacial film surrounding the dispersed water droplets. The main classes of demulsifiers are surface wetters, water droppers to

coalesce water droplets, treaters to flocculate submicron water droplets, and hybrids blended with solvents. The demulsifiers distribute themselves directly at the oil-water interface of the dispersed droplets where they act to reduce the thickness and tenacity of the film to the point where the interface can be ruptured by random collision or contact with other droplets. After the interface breaks, the released water must come in contact with other dispersed droplets so that water coalesces into larger droplets to eventually form a water layer. The rate of coalescence can be increased by agitation of the test fluid and the rate of separation as a discrete phase is enhanced by centrifugation.

Laboratory-scale tests are performed to identify the most effective and most rapidly acting chemical treatment package and dosage levels. If no historic information is known about successful treatment of similar waste streams, selection of chemicals is through a series of bottle or centrifugation tests as previously described. For example, if a chemical is required to break the water-in-oil emulsion, a range of demulsifier bases can be tested to identify which products enhance emulsion breaking and water drop formation. Simple 1:1 blends of the best bases identified can then be tested. By altering the chemical ratio the blend performance can be fine tuned. Based on the performance results, additional products to enhance water coalescence or oil quality can then be added to the mix and the effect tested. Ultimately finishing or polishing additives may also be included in the chemical blend, for example water wetters to encourage solids to separate from the emulsion or oil layers. Blending and interpretation of the many results is a complex process, which can produce an infinite number of possible blends and is regularly undertaken prior to any production waste treatment operations, by experienced chemists.

### **Chemical Selection Example**

Two samples of production waste were taken from a pit, 3.8 meters deep. The first sample was taken from the south section of a pit taken 8 to 9 m from the edge, at a depth of 1 m. A second sample was taken, approximately at the centre of the north section of the pit. Composition was determined using a heated centrifuge, spun at 1800 RCF, 85°C (185°F) for 60 min (Table 1). The results show that the waste contained significant amounts of water and solids and also an unresolved emulsion layer which would require chemical treatment to separate. Surfactants would be required to break the emulsion and encourage water separation. A water-wetting agent may also be required to water-wet the solids that stabilize the emulsion.

As a starting point the waste samples were treated with 4000 ppm of an acid-based demulsifier (Chemical A) and 4000 ppm of a demulsifying surfactant (Chemical B). The samples were centrifuged in the heated centrifuge at 85°C (185°F), at various RCF and residence times. The phase separation was noted and compared to that achieved without chemical addition (Figure 1). Without chemical addition and with low RCF, little water separation was observed. If

sufficient force and residence time is afforded, then up to 40% water separation can occur without chemical treatment. Addition of chemicals broke the emulsion at very low RCF and residence time; the water separation measured was low due to the high viscosity and density of the crude oil. As the RCF increased, the water droplets were more easily separated by centrifugation after chemical addition. The benefits of chemical treatment are more significant at low RCF and low reaction time as would be expected. The amount of solids separated by centrifugation did not improve with chemical treatment, with significant volumes remaining in the oil phase. Analysis of the solids recovered after centrifugation of the untreated sample showed that the solids were black and oil wet with a waxy coating. The solids separated after chemical treatment, although not greater in volume, were cleaner and comprised three distinct layers, showing that solids of different density, and therefore composition, were present in the sample. Water-wetting agents would be required in the chemical blend to enhance solids separation.

Ten possible products were tested using the heated centrifuge to determine the best agent to maximize solids drop with the minimum amount of time and force. Each wetting agent was mixed with 50% IPA for the first series of tests and 50% glycol for the second series of tests to reduce viscosity of the chemicals and enhance dispersion. The wetting agents were mixed by hand into sludge Sample 1 at concentrations between 500 and 4000 ppm. The samples then centrifuged at 800 RCF, 85°C (185°F) for 5 min. The volume of solids, water, emulsion and oil separated were recorded. The samples were then centrifuged for an additional 5 min to enhance separation. Less than 1% solids drop was detected in all cases. The samples containing the highest dose of wetting agent were then centrifuged for an additional 60 min to encourage solids separation (Figure 2). Eight of the 10 wetting agents showed increased solids recovery after increased centrifuge time, with Wetting Agent 10 giving over 70% recovery of the total available solids in this test. A plug of solids at the oil-water interface, however, was still present.

In a typical production waste operation, heating to 85°C (185°F) is followed by chemical addition and mixing. If the solids can be separated by G-force, a decanter centrifuge can often be used, with the overflow stream further treated to remove water and recover the oil phase. To simulate this in the laboratory, chemicals were added to Sample 1 and mixed for 10 sec using a laboratory Hamilton Beach overhead mixer. The sample was centrifuged under the same G-force (200 RCF) as would be experienced in a typical decanter, using the laboratory centrifuge for 10 min. The supernatant collected was decanted and the separated solids left at the bottom of the centrifuge tube. To simulate static separation conditions, the supernatant was added to bottles and kept in water bath at 85°C (185°F) for 1 hr and the phase separation noted. When the waste was treated with the chemicals previously identified (Chemical A, Chemical B and Wetting Agent 10) the water and solids separation was low at 2 and 0.5%, respectively. This showed that 1-G separation is unlikely to be successful in

separation of this waste stream and that centrifugation would be required.

The laboratory screening had therefore identified suitable chemicals for separation of the phases. The chemicals should be added downstream of any heating system, where temperatures of 85°C (185°F) should be reached to dissolve the waxes and thin the material. At this point addition of Wetting Agent 10 will allow the solids stabilizing the emulsion to become water wet. Chemicals A and B will break the emulsion and aid water drop from the loosed emulsion. A chemical dose of 4000 ppm for each product was found to be suitable for the samples tested on the laboratory scale. Downstream processing equipment, including centrifuges, will be required to enhance separation rate.

The chemical dose and separation efficiency must be monitored during full-scale treatment and adjusted based on feed variability and equipment performance. The laboratory techniques have been adapted and portable field testing kits developed to include all the necessary laboratory equipment to perform simple bottle and centrifugation tests on site. The success of the chemical and mechanical separation will be determined by the quality of the recovered oil. Specifications will be set on the amounts of solids and water permitted in the recovered oil. Typically 1 to 3% Basic Solids and Water (BS&W) are expected and this can be measured using the field testing kits and following standard methodology.<sup>8</sup> Analysis of the end-product quality during operation allows the chemical doses to be adjusted on a regular basis to ensure that product quality is maintained and re-processing is not required.

### **Mechanical Equipment Packages**

Mechanical equipment selection is governed by the nature of the waste to be treated; modular systems are beneficial in that only the modules required for a specific operation are utilized. Modular equipment also allows flexibility of process flow, permitting variations with the order of equipment used. Almost all production waste treatment requires a system for pumping the waste to the treatment modules, a source of heat to allow the waxes to dissolve and create a thin and pumpable liquid, a method of chemical injection, and equipment for phase separation. Following this principle discrete equipment modules were developed for production waste treatment.

Pumping production waste can be problematic, given that the material can contain a large quantity of semi-solid material and solids. A hydraulic pump with a mixing gate suspended from a crane and mounted on a trailer fitted with a diesel power unit has been developed. The pump contains a recirculation system to allow the waste to be homogenized prior to pumping to the treatment system. Lines are also available to feed steam into the pit to heat and liquefy the waste as required. The waste is then pumped from the pit either into storage tanks or directly into the treatment system. In cases where the material cannot be liquefied and pumped, traditional excavators are used to dig out the waste.

The fresh material is often preheated by combining with heated waste recycled from the downstream process. This

preheated feed is then screened through a shaker, fitted with a course screen to remove larger solids and debris to protect the downstream equipment. The underflow from the shaker is collected in a buffer tank which allows the flow rate to be controlled. The waste is then passed to a third module, where the material is heated to 85°C (185°F) or as otherwise determined in the laboratory tests. Typically the waste is heated indirectly using steam or hot water. The equipment module contains the necessary boilers and heat exchange equipment, be it spiral or plate heat exchangers or tanks fitted with heating coils, to liquefy the waste for movement through the processing equipment and stages.

Now that the material is hot and the viscosity reduced chemicals can be injected and mixed. The order of chemical addition in the process flow will be determined by the laboratory tests and types of chemicals identified. The chemicals can be added at discrete points in the treatment process or at a single injection point. A chemical injection module is available which contains chemical storage totes, chemical injection pumps and static mixers to allow chemicals to be injected at the correct dose and adequately mixed into the waste stream.

In some instances, especially with solids-laden waste streams, use of a decanter centrifuge may be able to assist the process efficiency by removing at least some of the solids present. Fine solids may require chemical flocculation to be removed in this manner.

If it is possible that the waste will achieve phase separation under gravity, another equipment module can be selected which will provide residence time for separation and allow recovery of the phases. This module may include traditional 3-phase static separators, liquid-liquid separators, API separators or tanks. Traditional separators may be modified to allow recovery of any solids that separate over this time, for example using fluidizers that slurry then pump out solids from the base of the separation unit. These separators can be linked to extraction systems to remove the volatile organic carbons generated from the heated sludge to ensure no release to the environment. The vapors are passed through mist impingers, knock-out pots and activated charcoal filters.

The recovered oil phase from the 1-G separators may require further treatment. High G-force centrifuges, for example disc stack centrifuges which can operate up to 5000 G, are often used as an oil-polishing stage to remove water and solids from the oil stream to produce oil that meets the BS&W criteria. The chemicals added in the process can assist this separation by encouraging emulsion split and solids wetting. The high temperatures of the process also aid phase separation. The disc stack centrifuge would constitute a separate equipment module.

### **Performance Example**

For another production operation, earthen pits were routinely used by refinery operations to store production waste. Often, once the pits were at maximum capacity, and unless treatment options were available, the material would be

incinerated. To allow recovery of the oil fraction, the water and solids phases must be separated from the oil phase. The oil must contain <1% BS&W to be accepted back into the refinery operation.

One of these pits was sampled and the samples sent for laboratory analysis. The samples were homogenized and the composition determined by retort and the heated laboratory centrifuge (Table 2). Using the retort technique, it was shown that the sample contained 45% oil, 54% water and 1% solids. This shows that in our equipment process, for every 100 bbl of waste processed, we should expect to produce 45 bbl of clean oil phase assuming 100% separation and recovery efficiency. Process efficiency can therefore be gauged based on product recovery. The large amount of water and low solids present suggested a weak emulsion. However, testing using the heated laboratory centrifuge, where the sample was spun at 1800 RCF, 95°C (203°F) for 60 min showed that at this temperature the waste emulsion is not fully resolved, even when G-force is applied (Table 2). 35% of the waste remained as an emulsion showing that chemical treatment would be required for separation and efficient oil recovery. Chemicals A and B (as discussed previously) were shown to be effective treatments for this particular waste treatment application also. Due to the low levels of solids in the waste, wetting agents were not required and only the acid and demulsifier were added over a range of concentrations at ppm level. Addition of 2000 ppm of Chemicals A and B produced maximum separation, when centrifuged at 85°C (185°F) for 60 min. Separation equivalent to the sample retort values was measured (Table 2).

Samples of the sludge were chemically treated and heated to 85°C (185°F) in a water bath and allowed to phase separation over a 60-min period. The separated oil phase was centrifuged at 800 RCF for 2 min using the heated laboratory centrifuge to determine the BS&W content. When used alone, Chemical A gave good phase separation, but the water content of the separated oil was above the customer's specification of 1% BS&W. Therefore a low concentration of demulsifier (Chemical B) was needed to assist in the separation process. It was determined that between 1500 and 2000 ppm Chemical A combined with between 250 and 500 ppm of Chemical B provided distinct and rapid phase separation and the separated oil had a BS&W of <1%. The testing suggested that the use of heat, chemical treatment and static separation could be used to achieve the customer's specifications. The use of a high G centrifuge to polish the oil phase is also recommended to increase efficiency and end-product quality.

On location, the material was transferred from the waste pit to large storage tanks using industrial vacuum trucks. A series of modules were selected and installed on location. The process flow is shown in Figure 3 and pictures of the individual modules are given in Figure 4. The waste was pumped into Module 1 where it was passed over a course shaker into a buffer tank to remove larger solids and debris.

The waste was then collected in a V-shaped augered tank used to feed the sludge at a constant rate using an open throat Moyno pump to a heating module. This second module

included a steam boiler and a spiral heat exchanger sized to increase the temperature of the waste from ambient to 85°C (185°F).

Once the hot waste material exited the heating module, it passed through the chemical injection module. This module was fitted with four chemical storage totes, four chemical injection pumps and a series of static mixers to ensure that the chemicals were properly dispersed. Due to the low solids content of the waste material, a decanter centrifuge module was not required in this case.

The fourth module comprised of a multi-phase separator. The heated and chemically treated waste passed into the separator; over the residence time of 60 min the action of the chemicals allowed the material to phase separate. Fluidizers at the base of the separator were used to remove any solids that settled. A series of weir plates enabled water and oil phase to be separated and pumped from the equipment. For this particular study, further treatment of the water and solids phases was not required by the client and the phases were either disposed or returned to the pit.

A disc stack three-phase centrifuge (Module 5) was required to polish the recovered oil phase and remove the final traces of solids and water.

To quantify the performance of the process, baseline measurements were determined where the waste material was passed through the equipment without chemical treatment. Through testing, it was shown that the disc stack separator was able to process the waste material efficiently without upstream 1-G separation; the 1-G separation module was bypassed, thereby decreasing the total processing time required. A buffer tank to control the feed rate to the centrifuge only was required. The setup of the disc stack centrifuge was adjusted to control the position of the oil/water interface to prevent large quantities of oil being separated with the water phase or water contamination of the oil phase. Figure 5 shows the quantities of oil, water and solids in the inlet feed material and the separated oil quality without chemical treatment.

The waste material pumped to the storage tank had a BS&W of 60.5% and contained more water and fewer solids than the previous sample provided for laboratory testing. This was because the pit being treated is active, with new waste material being added over time. Also variation of material in the pit itself may have contributed to this difference. The recovered oil from the centrifuge had a BS&W value of 1.2%, under steady state conditions. Although this was close to the oil specification required by the client, performance could not be guaranteed unless chemical enhancement was included in the process.

The lab testing showed that both Chemicals A and B would be required to enhance separation. Onsite testing using the field test kits showed that these chemicals were indeed suitable, but concentration ranges varied compared to those initially identified due to variation of the inlet feed material. 1000 ppm of Chemical A and 2000 ppm of Chemical B was injected into the waste, using the chemical injection module. BS&W between 0.4 and 3% was measured in the oil phase

from the disc stack centrifuge. The dose of Chemical A was increased from 1000 to 2000 ppm to destabilize the emulsion further. The concentration of Chemical B was reduced from 2000 to 1500 ppm as overdose of demulsification chemicals and high shear can in some instances result in emulsification rather than demulsification. The BS&W of the recovered crude was substantially reduced and more consistent at these treatment concentrations (Figure 6). The BS&W was always below the customer specification and shows the enhanced equipment performance with chemical addition.

Maintaining Chemical A at 2000 ppm, the demulsifier dose was further decreased from 1500 ppm to 0 and the effect on performance monitored. Figure 7 shows little change in the BS&W of the recovered oil at concentrations as low as 700 ppm. When no demulsifier was present, however, the BS&W increased to 1%. Therefore, optimal concentration for Chemical B is somewhere above 1 ppm and below 700 ppm.

Ultimately, this test using the optimal chemistry and equipment set up enabled 368 bbl of raw production waste to be processed and a total of 143 bbl of crude with less than 1% BS&W recovered. Third-party testing verified the BS&W content as 0.4% and the API viscosity of the crude as 22.9° at 23°C (74°F). Process efficiency was 90% for crude recovery. 189 bbl of water and 36 bbl of oily solids were also generated as waste.

This example clearly demonstrated the key role of chemistry in optimization of the production waste separation process. Chemicals can be identified in the laboratory to enhance separation but actual dosing rates must be determined on location during an optimization phase with onsite lab testing and variation of processing conditions. The performance demonstrated justifies future processing of larger waste volumes.

## Conclusions

This paper has illustrated that chemical selection is key to the successful treatment of production waste, allowing phase separation and oil recovery. Field operations have shown that proper characterization of the waste stream and analysis of representative samples will allow chemical packages to be developed specific to the chemical and physical characteristics of the waste material. Equipment modules have been described which enable feeding, heating, chemical injection, 1-G separation and centrifugation. Selection of the appropriate modules in the correct order, in conjunction with knowledge of the waste behavior with chemical treatment allows efficient systems to be deployed to treat the waste, overcoming the technical challenges associated with treatment of this material. In-field testing and analysis as well as monitoring chemical performance allow adjustments to the chemical system to optimize the process and to cope with batch variation.

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## Nomenclature

API	= American Petroleum Institute
BS&W	= Basic Sediments and Water
FTIR	= Fourier Transform Infra Red
G	= Gravitational Acceleration
GC-MS	= Gas Chromatography-Mass Spectrometry
RCF	= Relative Centrifugal Force
RCRA	= Resource Conservation and Recovery Act
ppm	= Parts per million
XRD	= X-Ray Diffraction

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**Table 1 – Composition of Production Waste Used to Develop Chemical Treatment Package.**

Sample	Oil (%)	Emulsion (%)	Water (%)	Solids (%)
1	43	10	40	7
2	62	5	28	5

**Table 2 – Composition of Production Waste in Case Study**

Method	Oil (%)	Emulsion (%)	Water (%)	Solids (%)
Retort	45	0	54	1
Centrifugation	40	35	25	Trace
Centrifugation w/chemical	45	–	54	1

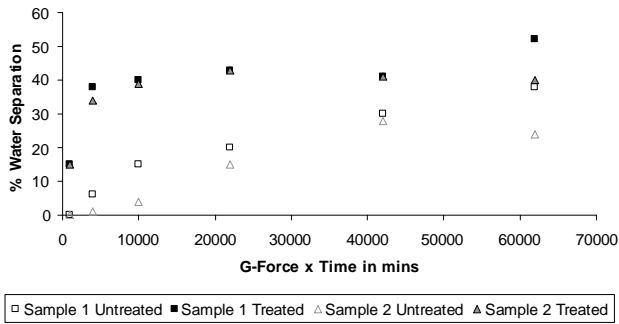


Figure 1 – Effect of Chemical Treatment on Water Recovery.

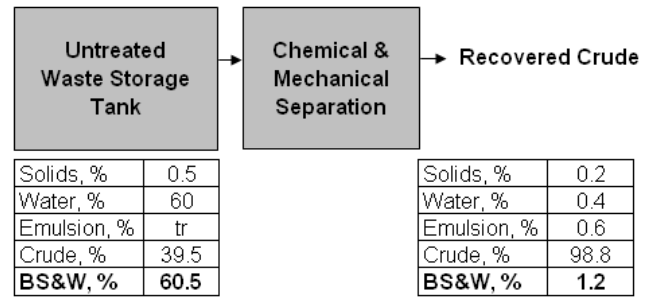


Figure 5 – Baseline Performance Results for the Production Waste Equipment Modules.

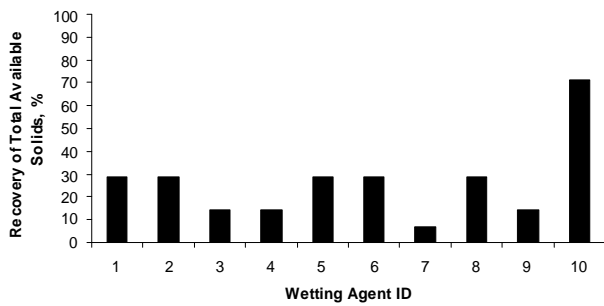


Figure 2 – Effect of Wetting Agent of Solids Separation.

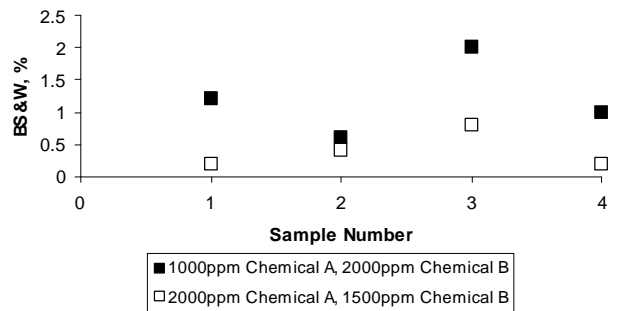


Figure 6 – BS&W Values for Oil Recovered from the Disc Stack Centrifuge at Two Different Chemical Doses.

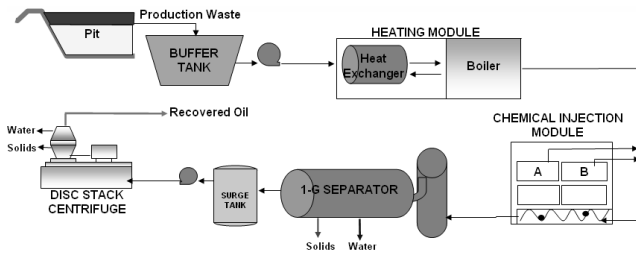


Figure 3 – Process Flow Diagram for Production Waste Treatment.

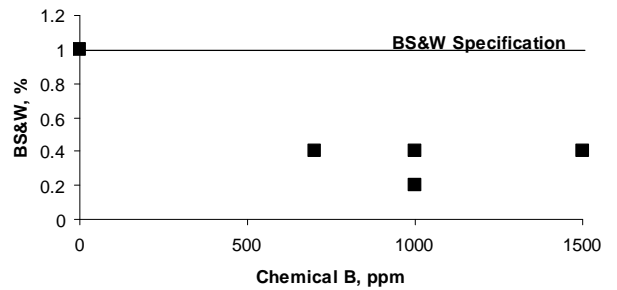


Figure 7 – Effect of Decreasing Demulsifier (Chemical B) Dose on Recovered Oil BS&W. Chemical A is maintained at 2000 ppm.



Figure 4 – Equipment Modules Utilized on Location to Treat Production Waste.