Effective Dehydration of Canadian Heavy Crude Oil and Dilbit
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Abstract
Heavy crude oils and diluted Bitumen (DilBit) continue to be a challenge to dehydrate for the Oil & Gas Industry. These challenges include reduced crude oil/formation water density difference, higher crude oil viscosity and often smaller water droplets due to the production techniques used for heavy crude oil production.

Other challenges include higher crude oil conductivity and increased crude oil emulsion viscosity formed by higher water cuts and increased solids content in the crude oil. Typically crude oil dehydration vessels use heat, retention time and AC type electrostatic dehydration technology. The AC technology produces limited voltage gradients and is not efficient for treating conductive crude oils, leading to the use of very large vessels and power units.

The traditional remedy to the above challenges often leads to high operating temperatures, high dosage of demulsifier chemicals, equipment fouling, production upsets and use of very large treaters. This leads to both higher operating expenditure (OPEX) as well as higher capital expenditure (CAPEX).

The use of combined AC/DC electrostatic technologies provides high bulk water removal efficiency in the weaker AC field combined with higher removal efficiency of small water droplets in the stronger DC field. Further improvements include amplitude modulated electrostatic fields, high frequency AC fields, improved electrode configurations as well as improved fluid distribution inside the electrostatic treaters.

More efficient dehydration and desalting processes provide potential for operating the treaters and desalters at lower operating temperatures and reduced dosage of demulsifier chemicals, in addition to the potential for using smaller treaters.

This paper describes improved crude oil dehydration using advanced electrostatic dehydration technologies and an efficient test method for optimized use of production chemicals, including case studies.

Heavy Crude Oil Properties.
Heavy crude oil normally refers to crude oils with an API gravity of 20 or less. There are also sub-definitions for very heavy oil (below API 14°) extra heavy oil (API 11° and below). Heavy crude oils also tend to be blacker in color, due to the higher Carbon/Hydrogen ratio.

DilBit is diluted Bitumen, where Bitumen is a black, highly viscous, sticky hydrocarbon mix often containing high solids content, with very high specific gravity (typically heavier than water). The dilution with a suitable solvent reduces both the DilBit density and viscosity. SynBit is a variant of DilBit where the Bitumen has been diluted with synthetic crude oil.

DilBit and SynBit have physical properties similar to heavy crude oil, with API gravities in the 14 – 16 range and often containing high Chloride and solids content. There is no actual formation water associated with DilBit and SynBit apart from SAGD steam, but often a Caustic solution is used to remove the Bitumen from Oil Sands and thus acts as an equivalent produced water.
The specific gravity of the crude oil is a function of the crude oil API°.

\[
\text{Sp. Gr. ( crude oil )} = \frac{141.5}{( \text{API} + 131.5 )}
\]

Crude oil categories:

- API > 30 Light crude oil
- 20 < API < 30 Medium crude oil
- API < 20 Heavy crude oil

In the following sections we will mainly be mentioning heavy crude oil, though DilBit and also SynBit are also included, having similar properties.

Some of the characteristic properties for heavy crude oil:

- High density (934 kg/m³ @ 20°C and higher)
- High viscosity
- Lower salinity of the formation water (produced water)
- Higher solids loadings (very high for DilBit and SynBit)
- Often higher crude oil conductivity
- Lower Gas / Oil ratio (nil for DilBit and SynBit)

This implies:

- Lower density difference between the crude oil and formation water phases and thus lower driving force for settling of water droplets
- Increased use of artificial lift, often creating stable crude oil emulsions in connection with the presence of fine solids
- Increased water cut downstream the FWKO, since the FWKO gets less efficient for heavy crude oils
- Need for higher operating temperature, larger treaters and use of higher dosage of demulsifiers
- Increased size for treater power units, alternatively use of lower voltage gradients due to the higher conductivity.
- Less efficient AC treaters.

The specific gravity of the formation water is a function of the amount of salt dissolved in the formation water. The types and quantities of salt dissolved in the formation water is formation specific. The major ingredients are normally Sodium and Chlorides and many times the formation water specific gravity can be approximated by:

\[
\text{Sp. Gr ( form water )} = 1.67 \times \text{Fr(salt)} + 1.00 \times (1 - \text{Fr(salt)})
\]

( where Fr(salt) is the weight fraction of salt )

Table 1 shows the density difference between the formation water and the crude oil, as a function of the crude oil API gravity and the formation water salinity (data valid at 40°C). The crude oil / formation water density difference increases with increased API gravity and formation water salinity. When the crude oil API gravity is 10 and the formation water salinity is nil, the density difference is almost zero (temperature dependent). As mentioned earlier, the addition of a suitable solvent reduces the density of the diluted crude oil / Bitumen and also reduces the oil viscosity. Choice of diluent is very important for compatibility.

An API 16° crude oil with 5% formation water salinity has about four times the density difference of a 10° crude oil with 2% formation water salinity. Similarly, when a 16° crude oil with 5% formation water salinity is desalted, the second stage desalter only has about half the crude oil / water density difference compared with the crude oil / formation water in the upstream 3-phase separators.

Figure 1 shows crude oil / formation water density difference for API 12°, 14° and 16° crude oils and formation water with 5%, 3% and 1% salinity, as a function of temperature. The density difference has an apparent maximum at 90°C.
The crude oil emulsion viscosity increases exponentially up to the crude oil emulsion inversion point, where the emulsion changes from oil continuous to water continuous, and where the emulsion viscosity drastically drops with further increased water cuts. Similarly, the crude oil emulsion specific heat, thermal conductivity and specific gravity will increase with an increased water cut. Unlike the emulsion viscosity, there is no ‘inversion point’ for the thermal properties of the emulsion and the thermal properties will eventually approach that of the water phase at high water cuts. It can also be noted that low salinity produced water has better thermal properties than high salinity produced water, which will have an effect when designing the heat exchangers in the crude oil train.

When Bitumen and a diluent are blended in different ratios to form different DilBit API gravities, the inversion point of the blend might happen at different water cuts, as shown in Fig 3 on our left. As can be noted, the DilBit viscosity drops sharply once the blend has become water continuous.
Heavy Oil / Formation Water Separability.

The speed of settling a water droplet in a crude oil continuous phase is governed by Stoke’s Law:

\[
V_s = \frac{d^2 (\delta_w - \delta_o)}{18 \nu}
\]

where:

- \( V_s \): settling speed in m/sec
- \( d \): diameter if the dispersed water droplet ( meter )
- \( g \): gravity constant, 9.81 m/sec²
- \( \delta_w \): density of the water phase ( brine ), ( kg/m³ )
- \( \delta_o \): density of the crude oil ( kg/m³ )
- \( \nu \): viscosity of the continuous oil phase, ( N sec / m² )

Fig. 4 shows separation efficiency reduction due to heavier crude oil, reduced salinity formation water and increased viscosity.

![Stoke's Factors](image)

The Stoke’s factor is a numerical representation of oil / water density difference divided by the emulsion viscosity, thus describing a relative number for water droplet removal efficiency from the crude oil for identical size water droplets. It is the work of the electrostatic treater to grow the water droplets in order to enhance the water droplet removal efficiency, and make the treaters more efficient and compact.

**Effects of Conductivity.**

The crude oil conductivity plays an important role for the function of the electrostatic fields inside the treaters. If the crude oil conductivity is very low, the electrostatic charge has difficulty reaching the dispersed water droplets and if it is very high the average applied voltage gradient is reduced through voltage decay.

The conductivity is measured in NanoSiemens per meter and the crude oil conductivity can be categorized into the following general categories:

- Low conductivity: below 500 nS/m
- Medium conductivity: 500 – 1000 nS/m
- High conductivity: 1000 – 2500 nS/m
- Ultrahigh conductivity: > 2500 nS/m

The conductivity of the crude oil is affected by the process temperature of the crude oil and as illustrated in Fig. 5 the crude oil conductivity can increase several times from ambient temperature to the process temperature in the crude oil treaters. It is thus important to measure the crude oil conductivity at the operating temperature and not only at ambient temperature. Cameron has developed a proprietary equipment for measuring crude oil conductivity at elevated temperatures. It has also been noted that when different crude oils are mixed, the conductivity of the crude oil mix often has a much higher conductivity. This is often experienced in refineries where the crude slate can include many different crude oils and where the blend in the slate can change frequently depending on the crude oil sourced by the refinery purchasing organization.

The effect of higher crude oil conductivity in an AC treater is a lower electrostatic field, resulting in less effective dehydration, since the smallest water droplets cannot be reached by the lower voltage fields. The alternative is using larger power units.
The AC/DC electrostatic treaters are more effective for treating conductive crude oils, especially the treaters having power units with modulated voltages and frequencies.

**Interface Control and Profiling.**

All crude oil dehydrators and desalters have some sort of level control, including a level sensor and an actuated valve in the separated water outlet. A common variant uses three Agar probes which sense the oil phase, the water phase and the interface. Thus the water dump valve can be regulated to maintain the interface between the upper and lower sensors. As the crude oil gets heavier (lower API gravity), the interface layer (rag) often becomes thicker and the triple probe interface sensors become less efficient.

An interface profiler provides a more efficient solution by profiling the density of the liquid phases inside the vessel over a larger span and thus can alert the operator of a rag layer built up. The profiler involves a higher capital investment, but can provide very valuable information about the dehydrator / desalter operation. For electrostatic treaters with adjustable / modulated power units, the information provided by the profiler can be used to adjust the settings of the power units so the rag layer can be treated with higher voltage spikes when thicker rag layers are detected.

**Solids and Fines.**

Due to their higher oil viscosities – lower API gravity crude oils carry higher amounts of solids since the flowing oil pulls more solids out of the formation. This can include both ultrafines as well as smaller solids. The Canadian Dilbits and SynBit carry rather significant loads of solids, which will put higher demands on the solids removal system in the treater.

The larger fines (small solids) will settle out in the bottom of the treaters and sometimes also on the support structure of the electrostatic grid system. The solids settled out in the bottom of the treater can be removed using a conventional mud wash system or use of the more effective Mozley solids removal system. Solids on the support rails inside the treater add extra weight and in the extreme case can build up to a point where the additional load exceeds the design load for the grid system, leading to grid system failures and extensive maintenance / repair. Significant solids build up can cause:

- volume reduction of the treater
- arcing between the electrodes and the solids
- build up of parasitic currents which lower the efficiency of the treater

Smaller fines can accumulate in the oil / water interface and assist in creating very tight emulsion layers (rag). This can be countered using an interface draw-off system, which will assist the operation but will generate the need of a separate treatment system for the interface draw-off material. For treaters using modulated power units, experience shows that subjecting the emulsion pad to intermittent voltage spikes can significantly reduce the rag layer and also contribute to a lower BS&W in the treated crude oil.

**Solids Removal Systems.**

Solids removal systems include:

- mud wash systems / sand jetting systems
- interface draw-off systems
- Mozley fluidizer system
The mud wash system is a water jetting system where some of the separated water is pumped back into the lower part of the treater in a number of jet nozzles and where in parallel a series of mud wash drain valves open up to allow drainage of the jetted solids and some water. The system includes pipe distribution manifolds, sand pan at the lowest point of the treater, wash water jets and a slurry drain system.

The interface draw-off system includes a number of mushroom type drain points located in the middle of the interface layer, using actuated valves or manual valves for draining the interface pad to a lower pressure system.

The Mozley fluidizer system is inserted through a nozzle in the bottom of the treater. It fluidizes and removes solids in a circular area of around 24” – 32” diameter around the inserted nozzle.

The solids removal systems need be operated frequently in order to prevent:
- solids build up inside the treater
- solids packing up and solidifying inside the treater

Experience shows that for DilBit and SynBit, the solids removal systems need to be beefed up in order to handle the increased solids load that most often follows these applications. Care shall also be done to consider an increased load on the support structure for the electrode plates and grids, pending on which electrostatic technology is used.

**Electrostatic Susceptibility Tester – EST®.**

Most crude oil dehydration processes utilize production chemicals to enhance the separation performance. The demulsifier chemical works on the oil / water interface, and by lowering the interfacial tension the coalescence of water droplets is improved. The interfacial tension plays a significant role in a mechanical separation process. A high interfacial tension provides stable water droplets but prevents coalescence of the droplets. A low interfacial tension assists water droplets coalescence but can easily cause droplet degradation if and when the droplets are sheared by fluid movement or sudden pressure drops.

The electrostatic field also lowers the interfacial tension and it is important that the combination of the demulsifier and the electrostatic field does not produce a too low of an interfacial tension (like below 2 dynes / cm), since this would cause water droplet breakup as the oil is flowing. It is thus vital that the demulsifier chemical is tested together with the electrostatic field, since many times the optimum demulsifier per a bottle test is not the optimum chemical for use in an electrostatic treater.
The Electrostatic Susceptibility Tester (EST) is a very effective tool for selection and optimum dosage of demulsifier chemical in an electrostatic treater and also an effective way to screen for optimum type of electrostatic technology to use. The EST uses 200 ml samples of an oil /water emulsion and can apply various AC, DC and AC/DC electrostatic fields. The EST provides valuable information about demulsifier and dosage rate selection. The EST imposes a voltage gradient between two electrode plates inserted into the crude oil emulsion and plots the resolution of the emulsion as a function of time. Thus by comparing the time required for resolution of the crude emulsion, the test engineer can provide valuable and reliable recommendations about the demulsifier selection and dosage rate.

![Fig. 10 Electrostatic Susceptibility Tester](image1)

![Fig. 11 Output of EST](image2)

The EST is a valuable tool for selection of electrostatic technology for green field application, and also a valuable tool for trouble shooting existing treaters. The EST can also be brought out into the field and can speed up the start up / commissioning of a new treater.

**ElectrostaticTreaters.**

Electrostatic treaters typically have upward vertical oil flow and include a few common elements for all electrostatic treaters:

- Inlet distribution system
- Electrode grids
- Power units
- Pressure vessel containment
- High voltage assembly with entrance bushing
- Collector pipe
- Level control
- Sand jetting / mud wash system

The AC treaters normally have electrode systems made up of an array of rods, like a grid system. The grids can be energized or grounded, with options for one, two or three hot grids. If three hot grids are used they are 120 degrees out of phase. Each energized grid requires its own power unit. Typical AC operating voltages today are 12.5 and 16.5 kVAC for the Bilelectric treaters, with a few more voltage taps for the TriVolt treaters. Inlet spreaders are either conventional pipe or open bottom spreader alt. the Bilelectric type shown in Fig. 13.

![Fig. 12 AC Treater type - TriVolt](image3)

![Fig. 13 AC Treater type - Bilelectric](image4)
The AC/DC treaters have two support rails for positive and negative electrode plates respectively. The electrode plates are oriented transverse the length of the treater and are installed vertically. Plates can be carbon steel, stainless steel or made of non-ferrous material. The latter material is beneficial when treating crude oils with higher water cuts where arc suppression is important. The AC/DC treater has a weaker AC field between the grounded water phase and the electrode plates, where bulk water removal takes place. The DC field is contained within the electrode area and provides a much stronger voltage gradient than the AC field and is thus capable of removing the small water droplets passed by the AC field. Typical voltage is 25 kVDC for un-modulated and up to 60 kVDC for modulated fields.

![Fig. 14 AC / DC Treatr](image)

**Electrostatic Forces.**

In a typical dispersion of water in crude oil, coalescence between water droplets occurs when droplets collide with sufficient energy to overcome the coalescence barriers. Barriers to coalescence include surface films adsorbed on the surface of the drops, fines dispersed around the water droplets, electrical double layer effects, and interfacial tension. The latter can be a driving force for coalescence, but also presenting an energy barrier that must be overcome before coalescence can occur. Chemicals can weaken surface films and moderate the electrical double layer and interfacial tension effects such that collisions result in coalescence. The use of chemicals can also lead to undesirable effects such as the production of interface pads (rag layers), particularly in systems with extensive skimmed oil recycling.

The introduction of electrostatic fields to the crude oil process marked a significant improvement in the treatment of water-in-oil dispersions. Electrostatic fields generate forces which assist in creating conditions for improved coalescence. There are three primary electrostatic forces – dipolar attraction, electrophoresis and dielectrophoresis. These forces are explained and illustrated below.

**Dipolar Attraction.**

Dipolar attraction is the electrostatic attraction force between oppositely charged ends of water droplets.

The dipolar water molecules tend to align themselves in an electrostatic field. A water droplet composed of such aligned molecules has both positive and negative ends and is thus polarized. These polarized droplets are attracted by neighboring water droplets. This dipolar attraction is:

- inversely proportional to the center to center distance between two droplets to the power of four
- proportional to the square of the electric field strength and to the droplet radius to the power of six

The dipolar attraction is more effective for high water cut crude oil emulsions, where the water droplets are larger and closer to each other. For low water cut crude oil emulsions, the dipolar attraction is less effective since the water droplets are smaller and farther apart. The dipolar attraction is common to all types of electrostatic fields.
**Electrophoresis.**
This is the electrical attraction between the charged electrode and oppositely charged water droplets in a uniform electric field.

Electrophoresis is the movement of charged water droplets within a uniform DC electrostatic field. Electrophoresis moves the water droplets horizontally between the electrode plates and provide the water droplets with many more collision opportunities. The electrophoretic attraction force is up to four orders of magnitude larger than the dipolar attraction force and is only available in the DC type fields.

**Dielectrophoresis.**
This is the movement of polarized water droplets in a non-uniform electrostatic field with the movement toward the direction of convergence of the field.

The dielectrophoresis is the weakest of the three electrostatic forces and is around half the strength of the dipolar attraction force. It depends on the field geometry and it is available in all field types.

**Electrostatic Fields.**
There are several types of electrostatic fields that may be used to enhance the water droplet coalescence inside the treater. These include the:
- alternating current (AC) field as in a Bilelectric and TriVolt treater
- AC high frequency field as in Bilelectric HF
- direct current (DC) field as in a Merecell treater
- combined AC/DC field in Dual Polarity™, ElectroDynamic Desalter™ and Dual Frequency™ technologies.

The Bilelectric HF, Dual Polarity, Dual Frequency and Electrodynamic Desalter technologies can also be modulated in several ways to further improve dehydration and desalting performance.

**AC Technology.**
Alternating Current (AC) crude dehydration technology is a 98 year old technology ( in 2013 ) and was for long the main technology used. It applies an alternating electric field at 50 to 60 Hz to the emulsion, causing the water droplets to stretch due to the dipolar attraction force and accelerating the water droplet coalescence by the attraction force between oppositely charged ends of the water droplets. The treaters using AC fields are quite effective for bulk water removal due to the nature of the dipolar attraction, but suffer performance degradation when lower water cuts are encountered since the dipolar attraction is weakened when the water droplets are spaced further apart. The AC treaters usually have horizontal electrodes made of steel rods.

Based on recent research and development, Cameron has now also introduced the modulated high frequency AC technology, which has been implemented in the Bilelectric™ HF treater. The high frequency AC field provides a higher average electrostatic field inside the Bilelectric HF treater with significant dehydration and desalting performance improvements, especially for crude oils with high conductivity. The use of high frequency AC electrostatic fields has already been patented and covers any and all types of AC treaters. The high frequency AC technology can easily be retrofitted on existing Bilelectric treaters, by simply upgrading the power units on the Bilelectric treater and with no modifications to the internals of the treater. See case studies for further details.

**DC Technology.**
It was early recognized that the DC fields provide superior coalescence due to their ability to utilize electrophoretic movement to enhance the water droplet collision rate. However, the application of a DC field to a water rich emulsion also resulted in electro-corrosion. This limited the application of DC treaters to processes involving refined products only ( with very low water content ).

**Dual Polarity Technology.**
Dual Polarity technology is a 41 year old technology ( in 2013 ), which was developed around 1972. In this process the incoming wet crude oil emulsion is first subjected to a weaker AC field for bulk water removal followed by a stronger DC
field where the remnant water droplets are removed. Since the DC field exists between the electrode plates only, the potential for electro-corrosion is eliminated. This design uses electrode plates oriented transverse to the treater length with alternate plates charged positive and negative. The design of the power supply is such that the positive and negative plates are charged on opposite half cycles, which thus provides twice the voltage gradient on the water droplets and eliminates the possibility of a sustained DC current.

The Dual Polarity technology subjects the crude oil emulsion to both an alternating (AC) field (50 to 60 Hz) and a higher voltage direct current (DC) field. In the DC field the water droplets acquire a charge and are accelerated towards the electrode plate of opposite polarity. Upon approaching the opposite polarity electrode, the droplet acquires the charge of that polarity and is then accelerated to the opposite electrode. As the droplet moves in the DC field (mainly due to the electrophoretic force), deform (due to dipolar attraction force), and collide, they become larger and eventually separate out of the DC field and settle down to the separated brine phase in the lower part of the treater. (Figure 13).

The size of a water droplet in equilibrium with an electrostatic field is inversely proportional to the strength of the field. Thus it is desirable to coalesce the water droplets with the lowest practical field strength. However, low intensity fields do not have sufficient energy to move and coalesce very small droplets. This often requires a compromise in field strength to try to optimize dehydration. To overcome this compromise and enable the treatment of high conductivity and low interfacial crude oils, a process was developed for modulating the AC/DC field. Modulated Dual Polarity technology has been used for over 25 years in crude oils considered difficult for conventional dehydration technology.

**Dual Frequency Technology.**

Treatment of crude oils with high conductivity and low interfacial tension requires a two-pronged approach for controlling the electrostatic field decay and interfacial tension. In an AC/DC treatment system, one set of plates experiences charge decay while the alternate set of plates is being charged. In high conductivity oil this decay can result in loss of the DC field as shown in Figure 17. To counter this the time between charges must be reduced. This is accomplished by increasing the frequency of the power source.

![Fig. 15 AC / DC Electrode Configuration](image)

![Fig. 16 Dual Polarity Treater](image)

![Fig. 17 Average Field Strength Increase with higher frequency](image)

![Fig. 18 Dual Frequency Treater](image)
To counter low interfacial tension, the droplet surface must be energized sufficiently to overcome it. This can be done by modulating the power at a frequency close to the resonant frequency of the dispersed water droplets. This bimodal frequency control is known as Dual Frequency. The power supply frequency (base frequency) is set to a value high enough to minimize field decay and is then modulated (pulse frequency) at a rate to energize the droplet surfaces. The result is high sustained field strength and highly energized drops which then readily coalesce. This base frequency can then be amplitude modulated as shown in Figure 19. The curve for this pulse frequency modulation can be varied.

![Sinusoidal Wave](image)

**Fig. 19** Frequency Modulation in the Dual Frequency System

**Fig. 20** Resonant Frequency Oscillation

Dual Frequency crude dehydration technology is 9 year old technology (in 2013). It uses the same electrode configuration as the Dual Polarity (Fig. 16) and can vary the base frequency and modulate the DC field depending on the crude specific characteristics. For upgrading a Dual Polarity unit to a Dual Frequency unit, the only physical changes are the power unit and electronic control system for adjusting the base frequency and modulating the DC field.

A physical system in resonance tends to absorb energy when the modulation frequency approaches the resonant frequency of the median water droplets. Thus relatively larger amounts of energy can be injected into the water droplets. This energy causes internal oscillation of the droplets and results in the deformation (see Fig. 20) of the water droplets, thus countering the interfacial tension holding them in spherical configuration. These deformed droplets then interact and coalesce readily. An added benefit is the temporary nature of this effect. Once the droplets leave the electrostatic field, they quickly lose the added energy through viscous effects and thus regain their interfacial tension and again become resistant to re-dispersion.

**Fluid Distribution.**

Another recent improvement in the treater design is the use of the HiFlo spreader, which can provide up to 35% better utilization of the vessel volume by elimination of fluid recirculation in the vessel and preventing bypass of the electric grid plates. The screen shot from the CFD analysis in the left picture shows areas with fluid recirculation and also crude oil bypassing the electrode plates closest to the vessel wall. The screen shot from the CFD analysis on the right, together with the flow pattern explanation in Fig. 22, show an improved fluid hydraulic design resulting in an improved utilization of the treater and thus a longer effective residence time.

![Conventional HiFlo™](image)

**Fig. 21** Open bottom box type and HiFlo spreader comparison

**Fig. 22** Clarification of the improved flow pattern using the HiFlo spreader
**Case Stories.**

1. **AC / DC SAGD Treaters**

   Treaters operating on SAGD DilBit in Alberta treat a blend of around API 16 equivalent crude oil. Due to the emulsion stability and high flow rates the treaters are large diameter vessels like 14’ ID with T/T length of 110’, operating around 131°C. The presence of fines in the feed and low water salinity adds extra difficulty in dehydrating the DilBit emulsion. Due to the high viscosity of the emulsion, the upstream process vessels will have limited water removal efficiency, thus providing a relatively high water cut in the feed to the treaters, often as high as 18 – 20 % v/v. The Dual Frequency treaters provide a treated DilBit with a BS&W at or below 0.5% v/v. Due to the size of the treaters, the electrostatic grids require double Dual Frequency power units operating on separate grid sections.

![Fig. 23 Typical SAGD DilBit process](image)

2. **Use of Higher Frequency AC Technology**

   Recent development work at the Cameron Technology Center in Houston has demonstrated the following benefits using high frequency AC power units on a heavy crude oil, compared with conventional AC Technology in a refinery Bilectric treater:
   - BS&W reduction from 0.9% to 0.3 %
   - Two fold increase in the treater flux

3. **Pilote Testing of API 14.2 DilBit**

   This 14.2 API gravity Canadian DilBit resulted from SAGD operation and dilution with a suitable solvent. The DilBit was further diluted to API 16.5 gravity, which provided better separability. Further dilution had no significant impact on water removal efficiency. This highly conductive emulsion was tested using different electrostatic technologies, which ranked the electrostatic technologies in water removal efficiency: AC → Dual Polarity → Dual Frequency (listed in increasing performance). Objective was to achieve 0.5% BS&W DilBit from an 11 – 12 % BS&W stable emulsion at 260°F. It turned out the voltage modulation was crucial for obtaining the driest DilBit and thus the highest and lowest applied voltages during modulation were important parameters for obtaining a 0.5% treated DilBit. Thus only the Dual Frequency technology was able to achieve the target BS&W.

4. **Upgrades in Electrode Material, Inlet Spreader and Electrostatic Fields**

   This crude oil treatment facility includes five AC/DC treaters in parallel service. The treaters were upgraded in two steps as indicated in the below table, initially only upgrading the inlet spreader system and the electrode material. After the addition of the Dual Frequency power units, the unit flow rate through the treaters had almost doubled.

<table>
<thead>
<tr>
<th>Technology</th>
<th>OT (°F)</th>
<th>Spreader</th>
<th>Electrodes</th>
<th>BOPD / Treater</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP, base case</td>
<td>140</td>
<td>Open bottom box</td>
<td>Steel</td>
<td>43,000</td>
</tr>
<tr>
<td>DP</td>
<td>140</td>
<td>OBB + wings</td>
<td>Composite</td>
<td>60,000</td>
</tr>
<tr>
<td>DF</td>
<td>140</td>
<td>OBB + wings</td>
<td>Composite</td>
<td>85,000</td>
</tr>
</tbody>
</table>

   Five treaters installed in parallel. Inlet 11% BS&W and outlet less than 1% BS&W. API 25 crude oil
5. **Upgrade from AC Technology to Dual Frequency Technology (API 24 crude oil)**

This upgrade of an offshore the electrostatic treater (Bulk Oil Treater) on a TLP in the Gulf of Mexico included the inlet spreader to HiFlo, the electrode plates to composite material and the Dual Frequency power unit. As a result of the upgrade the demulsifier injection could be reduced by 50%, resulting in approximately 600,000 USD savings annually.

6. **Sizing Comparison (API 18 and API 30)**

The below sizing comparison was based on API 30° crude oil with 12% salinity formation water and API 18° crude oil with 4% salinity formation water, using AC technology, Dual Polarity Technology (DP) and Dual Frequency Technology (DF) @ 50,000 BOPD, 0.2% BS&W. Using Dual Frequency technology the treater T/T length could be reduced by 36 – 38%.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Crude API°</th>
<th>Brine Salinity %</th>
<th>Inlet BS&amp;W %</th>
<th>Temperature °C</th>
<th>Vessel ID ft</th>
<th>Vessel L ft</th>
<th>Length Savings %</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>18</td>
<td>4</td>
<td>15</td>
<td>100</td>
<td>14</td>
<td>94</td>
<td>-</td>
</tr>
<tr>
<td>DP</td>
<td>18</td>
<td>4</td>
<td>15</td>
<td>100</td>
<td>14</td>
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<tr>
<td>DF</td>
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<tr>
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<td>12</td>
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<td>12</td>
<td>15</td>
<td>40</td>
<td>12</td>
<td>36</td>
<td>36</td>
</tr>
</tbody>
</table>

Table 2. Treater sizes required to treat 50,000 BOPD of wet crude down to 0.2% BS&W.

**Conclusions**

1. Heavy crude and DilBit are more difficult to dehydrate and desalt due to the smaller density difference between the formation water and the oil, higher oil viscosity, small water droplets, presence of fines and often higher oil conductivity.
2. Conventional AC treaters are less efficient in treating heavy crude oil and DilBit, due to lower voltage gradient, higher sensitivity to lower water cuts, etc.
3. AC/DC treaters are more efficient in treating heavy crude oil and DilBit, resulting in:
   a. Smaller treater size – especially important for offshore installations but also for projects with shipment size restrictions and for lower installation cost
   b. Possible use of lower operating temperature
   c. Possible use of higher flux in an existing vessel
   d. Lower BS&W in the treated crude and thus also lower salinity (PTB) of a desalted crude
   e. Reduced dosage demulsifiers and thus possibly cleaner water phase
   f. Possibility for a refinery to process higher concentrations of opportunity crudes
4. Modulated AC/DC treaters are more effective in treating conductive crude oils and resolving pad layers. In individual cases a modulated AC/DC treater can handle twice the flow rate of a conventional AC treater.
5. Solids removal systems are very important when treating heavy oil and DilBit, since solids will settle out inside the treaters. The alternative to solids removal system is a high maintenance cost from frequent internal inspections and manual solids removal.
6. Care shall also be exercised to verify the support system for the electrodes when treating heavy oil and DilBit with higher solids content, since the additional mechanical load from the solids will add an additional mechanical load to the support system.

**Acknowledgement**

We would like to thank Cameron for the opportunity to prepare and present this paper, our clients for feedback about the performance of their respective treaters and to SPE for their comments on this paper.
## Nomenclature

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Alternating current</td>
</tr>
<tr>
<td>API gravity</td>
<td>A measure of the crude oil specific gravity (API = 141.5 / s.g. – 131.5)</td>
</tr>
<tr>
<td>Barrel</td>
<td>Unit of crude oil volume, 159 liters</td>
</tr>
<tr>
<td>Bitumen</td>
<td>Black and sticky hydrocarbon mixture with high viscosity and high density</td>
</tr>
<tr>
<td>BOPD</td>
<td>Barrels of crude oil per day – crude oil flow rate</td>
</tr>
<tr>
<td>BS&amp;W</td>
<td>Bottom sediment and water, measure of the sum of impurities in the crude oil</td>
</tr>
<tr>
<td>CFD</td>
<td>Computational Fluid Dynamics</td>
</tr>
<tr>
<td>DC</td>
<td>Direct current</td>
</tr>
<tr>
<td>Dehydration</td>
<td>Removal of insoluble water from the crude oil</td>
</tr>
<tr>
<td>Desalting</td>
<td>Removal of water soluble salts from the crude oil</td>
</tr>
<tr>
<td>Emulsion</td>
<td>Continuous oil phase with dispersed water droplets (alt. oil droplets disperse in continuous water phase)</td>
</tr>
<tr>
<td>Flux</td>
<td>Relative flow rate in an electrostatic treater. Measured in barrels of oil per day and square foot of cross sectional area at the treater mid point</td>
</tr>
<tr>
<td>Formation water</td>
<td>Water (often containing a significant amount of salt) existing in the oil formation below the oil layer</td>
</tr>
<tr>
<td>FWKO</td>
<td>Free water knock out drum, process vessel removing free water from the crude oil</td>
</tr>
<tr>
<td>Metercell</td>
<td>DC Treater for refined products.</td>
</tr>
<tr>
<td>Non-ferrous</td>
<td>Material not based on steel</td>
</tr>
<tr>
<td>Pad</td>
<td>Interface layer (emulsion) between the oil and water phases inside the treater</td>
</tr>
<tr>
<td>Power unit</td>
<td>Electric unit providing high voltage to the electrostatic grids inside the treater, including junction box, transformers, rectifiers, etc.</td>
</tr>
<tr>
<td>PTB</td>
<td>Pounds of salt per thousand barrels of crude oil, measure of crude oil salinity</td>
</tr>
<tr>
<td>SPE</td>
<td>Society of Petroleum Engineers</td>
</tr>
<tr>
<td>TAN</td>
<td>Total Acid Number of the crude oil</td>
</tr>
<tr>
<td>Water cut</td>
<td>Percent water by volume in the crude oil</td>
</tr>
<tr>
<td>WHO</td>
<td>World Heavy Oil</td>
</tr>
</tbody>
</table>
REFERENCES

M.L. Chawla, Kuwait Oil Co.  
Field Desalting of Wet Crude in Kuwait  
SPE 15711

Anne Finborud, Mator AS, Mark Faucher, and Erik Sellman, Alfa Laval  
New Method for Oil Droplet Growth for Separation Enhancement  
SPE 56643

Advanced Electrostatic Technologies for Dehydration of Heavy Oils  
SPE 97786

Erik Sellman  
Flexible Heat Exchange Solutions Fit For Lifetime Operation of Oil & Gas Production Facilities  
Compact Heat Exchangers and Enhancement Technology Conference, Crete, 2003

Gary Sams, NATCO  
Dehydrate Heavy Oil with Advanced Electrostatic Process  
AIChE

In-Field Emulsion Treatability Test with The Electrostatic Susceptibility Tester  
Josep Lee (SPE) and Ted Frankiewices (SPE), NATCO Group Inc, Mohd Zaki Ismail, Mona Liza Anwar, Petronas  
SPE 102221

Electrostatic Demulsification on Crude Oil: A State-of-the-Art Review  
Christine Noïk (SPE), Jiaqing Chen and Christine Dalmazzone (SPE), Institute Français du Pétrole  
SPE 103808

Jon Moretto, Jacobs Consultancy  
Bitumen Processing – A Guide to Crude Unit Revamps  
NPRA Annual 2011: AM-11-48,

S. Pavan Kumar Mandewalkar, Dallas Douglas and Nicholas H. Blackman, Cameron Process Systems  
High Frequency Technology Shows Significant Improvements over Conventional AC Electrostatics Desalter  
AFPM Annual 2012: AM-12-19

John M. Walsh, Shell E&P, Gary W. Sams and Joseph Lee, Cameron  
Field Implementation of New Electrostatic Treating Technology  
OTC 23200, 2012

Erik Sellman, Gary Sams, S. Pavan K. Mandewalkar, Cameron Process Systems  
Use of Advanced Electrostatic Fields for Improved Dehydration and Desalting of Heavy Crude Oil and DilBit  
WHOC12-159, World Heavy Oil Conference, Aberdeen, 2012