Improved Dehydration and Desalting of Mature Crude Oil Fields
Erik Sellman, SPE, Gary Sams and S. Pavan Kumar Mandewalkar, SPE, Cameron Process Systems

Abstract
Mature crude oil fields most often contain higher water cuts and higher content of fines. The combination of a large population of water droplets and fines form very stable crude oil emulsions that are difficult to break.

The higher water cuts provide higher crude oil emulsion viscosity because of the larger population of small water droplets, often leading to a need for higher operating temperatures, frequent production upsets and high demulsifier dosage.

Another challenge is arcing between electrodes as a result of the higher water cuts. Typically older crude oil dehydration and desalting treaters use AC type electrostatic technology, which are less effective in treating crude oils with higher water cuts.

The use of combined AC / DC electrostatic technology provides a two prong approach where bulk water is removed in a weaker AC field and remaining smaller water droplets are removed in a stronger DC field. Further improvements to the AC/DC treaters include use of composite electrode plates, modulated electrostatic fields as well as improved fluid distribution inside the treaters.

AC / DC treaters provide an attractive opportunity for retrofitting existing AC treaters in mature fields and make the treaters more suitable for dehydrating the crude oil emulsions from these fields.

This paper describes new enhanced electrostatic dehydration technologies suitable for treating higher water cut crudes from mature fields, efficient test methods for optimized usage of production chemicals and selection of electrostatic technologies, including case studies.

Mature Field
Most crude oil wells initially produce a dry crude oil. As the field matures the crude oil production will reduce and the produced water production will increase. Fig. 1 shows a typical production profiles for crude oil and produced water.

After a couple of years (formation and production flowrate dependent) the formation water production has exceeded the crude oil production. The emulsion in the free water knock out drum (FWKO) thus changes from oil continuous to water continuous.

The emulsion in the process vessels downstream the FWKO will also contain a higher population of water droplets, with a resulting higher crude oil viscosity. At 30% water cut the emulsion may have 40% higher viscosity compared with dry oil viscosity. The higher emulsion viscosity will affect the performance of the downstream separators and treaters. Historically the design points for max oil, max water and max fluids do not coincide in time and many times equipment will be operated with much higher water cuts than originally designed for.

Fig. 1 Typical production profile
The increased solids and fines content in the produced fluids from mature fields also puts a higher solids loading on the treaters and typically the largest solids settle out in the FWKO and the smallest fines settle out in the electrostatic treaters where the process temperature is the highest and the retention time the longest. Some of the smaller fines might also get caught in the interface layer between the crude oil and produced water phases, thus stabilizing the emulsion rag layer. Solids handling systems in the electrostatic treaters are described further down in this paper.

Enhanced oil recovery with polymer flood recovers additional volumes of oil. However when the polymer rich produced water arrives at the oil treatment facility, there will be additional challenges in the form of plugging heat exchangers, deposits on fire tubes in heater treaters, etc.

**Crude Oil Dehydration and Desalting Processes**

Crude oil dehydration and desalting processes are all about removal of small immiscible water droplets from the crude oil. In the case of crude oil desalting, the dehydration process is preceded by a water wash and mix step where the brine in the crude oil is diluted with lower salinity wash water. The wash water does not necessarily have to be fresh water, in the case of pre-salt crude with extremely saline formation water the wash water can be de-oxygenated seawater.

**Fluid Properties.**

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

There are also sub-definitions for very heavy oil ( below API 14° ) extra heavy oil ( API 11° and below ). Heavy oils also tend to be blacker in color, due to the higher Carbon / Hydrogen ratio.

Some of the characteristic properties for heavy crude oil:

- High density ( 934 kg/m³ @ 20°C and higher )
- High viscosity
- Lower salinity 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 )

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 formation water salinity ( data valid @ 40°C ). When the crude oil API gravity is 10 and the formation water salinity is nil, the density difference is almost zero (temperature dependent).

The density difference increases with increased API gravity and formation water salinity. An API 26° crude oil with 15% formation water salinity has about twice the density difference of an 18° crude oil with 7% formation water salinity. Similarly, when a 22° crude oil with 25% formation water salinity is desalted, the second stage desalter only has about one third of crude oil / water density difference compared with the crude oil / formation water in the upstream 3-phase separators.

Figure 2 shows crude oil / formation water density difference for API 30°, 22° and 14° crude oils and formation water with 15%, 11% and 7% 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 reduces with 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.

### Crude Oil / Formation Water Separability.

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

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

where:
- \(V_t\): settling speed in m/sec
- \(d\): diameter of the dispersed water droplet (meter)
- \(\delta_w\): 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)

### 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 due to voltage decay.
The crude oil conductivity, measured in NanoSiemens per meter, can be divided into the following general categories:

- **Low conductivity:** below 500 nS/m
- **Medium conductivity:** 500 – 1000 nS/m
- **High conductivity:** 1000 – 2500 nS/m
- **Ultra high conductivity:** > 2500 nS/m

The conductivity of the crude oil is affected by the process temperature and as illustrated in Fig. 4 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 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 is a weaker AC electrostatic field, resulting in less effective dehydration, since the smallest water droplets cannot effectively be reached by the lower voltage gradient. The alternative is using larger power units.

![Fig. 4 Crude oil conductivity as a function of the crude oil temperature](image1)

![Fig. 5 Voltage decay as a function of increased crude oil conductivity](image2)

**Interface Control and Profiling.**

All crude oil dehydrators and desalters have some type of level control system, including a level sensor and an actuated valve in the separated water outlet. A common variant includes three Agar probes which sense the oil phase, the water phase and the interface. Thus the water dump valve is 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 Agar probes 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 valuable information about the dehydrator / desalter operation. For electrostatic treaters with 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 resolved 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 tends to pull 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 require the inclusion of special features on the dehydrator vessel.

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 a more effective solids removal system, such as Mozley Fluidizer or HydroTrans. 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 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

**Electrostatic Susceptibility Tester™.**

Most crude oil dehydration processes utilize production chemicals to enhance the separation performance. The demulsifier chemical works on the water droplet surface 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 lower the interfacial tension and it is important that the combination of the demulsifier used 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 when 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.

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 or right sizing the chemical use of an operating treater. In either case, the optimized demulsifier dosage will have a positive effect on the OPEX of the facility.

**Electrostatic Treaters.**

Electrostatic treaters typically have upward vertical oil flow and include a few common elements to 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 and each energized grid requires its own power unit. Typical AC power unit secondary output voltages are 14, 16⅔, 18, 20 and 22 kVAC, with a tendency towards lower voltages used for heavier crude oils.

The AC/DC treaters have two sets of support rails for positive and negative electrode plates respectively. The electrode plates are oriented transverse the length of the treater and are installed vertically. The plates can be made of steel or of composite material. The latter material is beneficial when treating crude oils with higher water cuts where arc suppression is important.

The AC/DC treaters have a weaker AC field between the electrode plates and the grounded water phase, where bulk water removal takes place. The stronger 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 24 kVDC for un-modulated and up to 60 kVDC for modulated fields.
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.

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 Dielectrophoretic force 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
- direct current (DC) field
- combination AC/DC field as in Dual Polarity™, ElectroDynamic Desalter™ and Dual Frequency™ technologies.

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

AC Technology.
Alternating Current (AC) technology is a 97 year old technology (in 2012) and was for long the main technology used for crude dehydration. It applies an alternating electric field at 50 to 60 Hz to the crude oil emulsion, causing the water droplets to stretch due to the dipolar attraction force and improving 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.

DC Technology.
It was early recognized that 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 and low electrical conductivity). The Metercell DC treater is used for polishing refined products such as gasoline, Diesel and Kerosene.

Dual Polarity Technology.
Dual Polarity technology is a 40 year old technology (in 2012), 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 vertically oriented electrode plates 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 move 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 11).
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 the dehydrration process. 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. The Modulated Dual Polarity technology has been used for over 25 years on crude oils considered difficult for conventional dehydration technology, especially in the Canadian DilBit treatment.

**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. To counter this the time between charges must be reduced. This is accomplished by increasing the frequency of the power source, as shown in Figure 14.

![Figure 14. Average Field Strength Increase with higher frequency](image1.png)

![Figure 15. Dual Frequency Treater](image2.png)

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 lower than the resonant frequency of the Stokes 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 electrostatic 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 16. The curve for this pulse frequency modulation can be varied.

![Fig. 16 Frequency Modulation in the Dual Frequency System](image3.png)

Dual Frequency crude dehydration technology is 8 year old technology ( in 2012 ). It uses the same electrode configuration as the Dual Polarity ( Fig. 13 ) 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, power wiring and electronic control system for adjusting the base frequency and modulating the DC field.

**Composite Electrodes.**

The standard material for the electrodes in an AC/DC treater is steel. Composite electrodes were developed to provide better tolerance for higher water cuts in the electrode area, especially for use in electrodynamic desalters ( EDD ). Experience has also shown that the composite electrodes provide better dehydration by providing a gradual electrostatic field and also subjecting the crude oil emulsion to a longer exposure time in the intense voltage field.
Using composite electrodes, the treater can handle about twice as high water cut compared to treaters using steel electrodes. Composite electrodes suppress arcing from the high water cut, since the composite electrodes have less charge on the electrode edges.

**Fluid Distribution.**

Another recent improvement in the treater design is the use of the Hi-Flo™ spreader, which can provide up to 35% better utilization of the vessel internal volume by elimination of fluid recirculation in the vessel and preventing bypass of the electric grid plates. The below 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. 19, show an improved fluid hydraulic design resulting in an improved utilization of the treater and thus a longer effective residence time.

**Case Stories:**

1. **Upgrade from Steel Electrodes to Composite Electrodes (API 20°)**

<table>
<thead>
<tr>
<th>Flux (\text{BPD/ft}^2)</th>
<th>Inlet BS&amp;W %</th>
<th>Outlet BS&amp;W % Steel Electrodes</th>
<th>Outlet BS&amp;W % Composite Electrodes</th>
<th>BS&amp;W Reduction %</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>15%</td>
<td>1.2</td>
<td>0.40</td>
<td>0.82</td>
</tr>
<tr>
<td>53</td>
<td>15%</td>
<td>1.3</td>
<td>0.75</td>
<td>0.55</td>
</tr>
<tr>
<td>76</td>
<td>15%</td>
<td>1.2</td>
<td>0.60</td>
<td>0.60</td>
</tr>
<tr>
<td>107</td>
<td>15%</td>
<td>1.2</td>
<td>0.60</td>
<td>0.60</td>
</tr>
</tbody>
</table>

2. **Upgrade of Offshore Bulk Oil Treater (API 27°) to Dual Frequency Technology**

   This upgrade of the 148,000 BOPD electrostatic treater on a deepwater tension leg platform (TLP) in the Gulf of Mexico included the inlet spreader, the composite electrode plates and the Dual Frequency power unit. As a result of the upgrade the demulsifier dosage could be reduced by 50% while maintaining the original flowrate and BS&W, resulting in an annual saving of approximately 600,000 USD.
3. **Upgrade of Existing Crude Oil Treaters using Composite Electodes API 25°**

The original crude oil treatment complex included five identical crude oil dehydrators with steel electrodes and open bottom box type spreaders, operating at 43,000 BOPD per treater at 140°F operating temperature. The inlet to each treater contained 11% BS&W with an outlet specification of less than 1% BS&W. Three treaters were retrofitted with composite electrodes and wings on the box spreaders, which allowed a 17,000 BOPD increase in process rate to 60,000 BOPD per treater at constant crude oil quality. The upgrade to Dual Frequency technology provided an additional 25,000 BOPD capacity increase to 85,000 BOPD per treater.

4. **Upgrade of Existing Crude Oil Treaters to Dual Frequency, API 14 – 25**

<table>
<thead>
<tr>
<th>Crude ID</th>
<th>API°</th>
<th>Temp (°F)</th>
<th>Feed BS&amp;W (%)</th>
<th>Flux (BOPD/sq ft)</th>
<th>Dual Polarity BS&amp;W (%)</th>
<th>Dual Frequency BS&amp;W (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Venezuela</td>
<td>25</td>
<td>150</td>
<td>11</td>
<td>200</td>
<td>1.8</td>
<td>0.6</td>
</tr>
<tr>
<td>Venezuela</td>
<td>17</td>
<td>280</td>
<td>28</td>
<td>94</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Wyoming</td>
<td>24</td>
<td>130</td>
<td>11</td>
<td>100</td>
<td>1.45</td>
<td>0.85</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>23</td>
<td>135</td>
<td>11</td>
<td>75</td>
<td>1.35</td>
<td>0.5</td>
</tr>
<tr>
<td>Brazil</td>
<td>14</td>
<td>240</td>
<td>5</td>
<td>80</td>
<td>0.5</td>
<td>0.27</td>
</tr>
</tbody>
</table>

5. **Production Increase for Dehydrating API 20.6 Crude Oil**

Process tests carried out at the Cameron Technology Center in Houston, Texas, verified that the crude oil dehydration capacity (flux) can be improved for a 12’ x 80’ treater dehydrating API 20.6° crude using AC/DC technologies in lieu of conventional AC technology.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Treatment Capacity BOPD</th>
<th>Capacity Increase BOPD</th>
<th>Capacity Increase %</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>81,600</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DP</td>
<td>102,000</td>
<td>20,400</td>
<td>25%</td>
</tr>
<tr>
<td>DF</td>
<td>175,500</td>
<td>93,900</td>
<td>125%</td>
</tr>
</tbody>
</table>

**Conclusions**

Upgrading existing crude oil dehydration treaters to AC/DC technology can provide the following benefits:

a. **Production benefits:**
   i. higher flow rate in an existing vessel
   ii. lower BS&W and salinity in the treated crude
   iii. improved dehydration of high water cut crude oils
   iv. improved resolution of rag layers

b. **OPEX savings:**
   i. reduced operating temperature and BTU savings
   ii. reduced demulsifier dosage

**Acknowledgement**

The authors would like to thank Cameron for this 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>Term</th>
<th>Definition</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>BWPD</td>
<td>Barrels of water per day – formation water flow rate</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>SAGD</td>
<td>Steam Assisted Gravity Drain – production technique for Bitumen</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>

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