

# **New Challenges in Oil Dehydration Improved by Dual Frequency® Electrostatic Process**

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This paper was presented at the SAOGE 2008 in Dammam, November 17-19, 2008. It was selected for presentation following review of information contained in the abstract submitted by the authors.

## **ABSTRACT**

With the world's production of crude oil becoming heavier, the need for efficient, compact separation and dehydration is essential. Application of improved electrostatic dehydration technologies has the potential to have a major impact in reducing oil production costs. Improved hydraulic efficiency, the use of alternative electrodes and the application of dual frequency modulation to the electrostatic power supply shows significant production benefits. Nearly a 100% improvement in the hydraulic efficiency of electrostatic coalescers has been achieved by utilising an effective flow distribution and collection system. A 30% dehydration improvement is achieved by the use of electrodes constructed of alternative materials. A 100% dehydration improvement in the capacity and performance of existing oil dehydrators have been demonstrated from an improved, patented electrostatic power supply utilizing a dually modulated electrostatic field. This patented power supply coupled with Load Responsive Controller (LRC®) allows the operator to adjust the energy supplied to the drop interface as necessary for overcoming interfacial tension while also adjusting the time available for electrostatic field decay as required to minimize the effects of oil conductivity. It has not previously been possible to directly address either of these parameters. It has been shown in both laboratory and field tests that significant improvement in dehydration results from application of these techniques.

These results have been confirmed at a production facility in North Slope Alaska, USA handling 48,000 bopd of a heavy to medium gravity crude oil with about 5% solids. This oil was processed by a 10 ft. diameter x 55 ft. long electrostatic dehydrators using combined AC/DC electrostatic technology. The outlet BSW dropped to 0.2% from 1% while the vessel capacity was increased from 40000 bopd to 48000 bopd. Also, at another facility in Gulf of Mexico, an AC/DC Treater which processed 48000 bopd of medium gravity crude was retrofitted with Dual Frequency® power system. A 40% reduction of Demulsifier usage while maintaining or exceeding the required oil specification was confirmed. These fields demonstrated conclusively that this Dual Frequency® electrostatic system provides producers and refiners with the ability to dehydrate and/or desalt oils more efficiently and to better process more difficult crudes.

## **INTRODUCTION**

Dehydration of heavy crude oils presents unique challenges due to high viscosity, the presence of suspended solids and semi-soluble components, and the limited differential density for driving the sedimentation-based separation. Early studies have been made of traditional electrostatic technologies and their capability to meet these challenges<sup>1</sup>. This paper shows how oil dehydration can be improved by an enhanced technology and in particular enhanced electrostatic dehydration technology.

Initially, utilising a South American oil facility, illustrated in Figure 1, two of the five vessels were retrofitted with an improved distribution and electrode system. A third vessel received an improved oil distributor and enhanced electrostatic dehydration technology. The

application of these technologies was intended to quantify at an operating facility the improvements that could be achieved in a commercial oil dehydration process and to demonstrate the robustness of the equipment, and establish confirmation of laboratory test results.

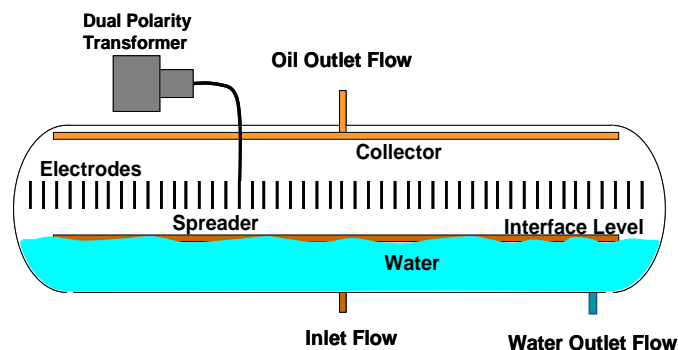


**Figure 1: South American Production Facility**

The commercial production facility shown includes five oil dehydration vessels operating in parallel. Each horizontal dehydrator is 10 ft OD x 45 feet long and utilises Dual Polarity<sup>®</sup> AC/DC electrostatic technology. Three vessels contained open bottom inlet spreaders, steel high voltage electrodes and pipe collectors. The other two vessels contained similar spreaders and collectors but used composite high voltage electrodes, in lieu of steel. All five vessels were equipped with Dual Polarity<sup>®</sup> (AC/DC), 150 kVA transformers operating on 480 volt, single phase power.

## DUAL POLARITY (AC/DC) TECHNOLOGY

All vessels use Dual Polarity electrostatic technology, as shown in Figure 2, to treat the inlet oil/water mixture.<sup>2</sup>



**Figure 2: Dual Polarity Vessel Configuration**

Design features include inlet spreaders to distribute the incoming fluid evenly along the length and across the width of the vessel. The spreaders are open-bottom box-type, which

permits bulk separation of free water and solids. Oil/water interface is established just below the spreader holes so the inlet fluids are distributed into the oil phase. An array of high voltage electrodes are arranged just above the centreline of the vessel. These electrodes are arranged in parallel at a spacing of 6 inches. They are 6 inches high and at their ends approach within 6 inches of the vessel wall. Alternating electrodes are energised with a positive voltage and adjacent electrodes are energized with a negative voltage. The positive and negative voltages are supplied from the 100% reactance, 23 kV (rms) transformers. A single collector, located longitudinally along the top of the vessel, contains a series of holes optimised to ensure uniform collection along the length of the vessel. A single outlet nozzle is located near the centre of the vessel.

## **PRODUCTION PARAMETERS**

The facility processes 27.1°API oil at flows between 45,000 bopd to 60,000 bopd per vessel with inlet water cut typically ranges between 20 to 30%. The operating temperature is maintained at 140°F and the operating pressure is 80 psig. At operating temperature the dry oil viscosity is 8.9 cp. The outlet specification is less than 1% BS&W and is routinely met by the dehydration process. The three vessels with steel electrodes can typically process about 45,000 bopd to meet the 1% BS&W target. The two vessels equipped with composite electrodes are capable of handling about 60,000 bopd and continue to meet the target BS&W.

## **COMPOSITE ELECTRODES**

Electrostatic coalescence generally proceeds through a mechanism of drop polarization, alignment of the polarized drops, and “chaining” of these drops along the lines of force of the electrostatic field. These conductive chains lead to frequent electrical discharges or arcing between the electrodes. The arcs are a normal part of the process, and because they are submerged in oil, they do not produce any damage. However, a steel electrode array is momentarily discharged by an arc, and if the arcs occur with sufficient frequency (as in a wet emulsion); the electrodes may be discharged for a sufficient duration for slippage of process fluids without adequate exposure to the field. Composite plate electrodes may be used to increase the water tolerance of the system under such conditions. These electrodes consist of plates of composite (fiber reinforced plastic) construction with graphite or carbon embedded in the central portion of the plate to impart conductivity along the length of the plate. The remainder of the plate contains filler materials that lead to the adsorption of a layer of water on the plate surface. This adsorbed water layer then becomes the conductive medium along the height of the plate. Since such an adsorbed layer is quite resistive, any arcing that occurs is quickly quenched. As a result, only the area in the immediate vicinity of the arc is discharged and slippage is almost eliminated.

The non-metallic, composite electrode array overcomes many of the limitations of steel electrodes by providing intrinsic arc-quenching capabilities along with self-adjusting field strength gradation. Composite electrodes permit the processing of oils of high water content and conductivity that were unable to be reliably processed using conventional technology. As part of the facility upgrade the steel electrodes were removed from three vessels and replaced with composite electrodes.

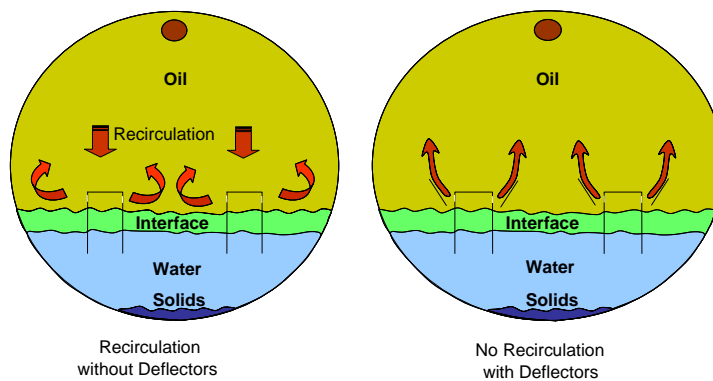
## **OIL DISTRIBUTION**

In 2001 NATCO conducted a series of CFD and lab experiments to document the hydraulic efficiency of our oil/water spreaders. These studies conclusively showed the energy of the

oil/water mixture is sufficient to carry each jet of oil to the facing vessel wall where it is deflected upward by the vessel curvature. Further investigation indicated that light oils with less viscosity tend to remain as a well-defined stream while heavier oils with higher viscosity initiated movement of adjacent fluid and disbursed more quickly. In both cases, however, unwanted parasitic circulation result from the orifice jets and produced gross counter-flow in the main body of the vessel. The results were not only fluid flow in the wrong direction through the electrodes, but a reduction in the apparent vessel residence time by 45%.

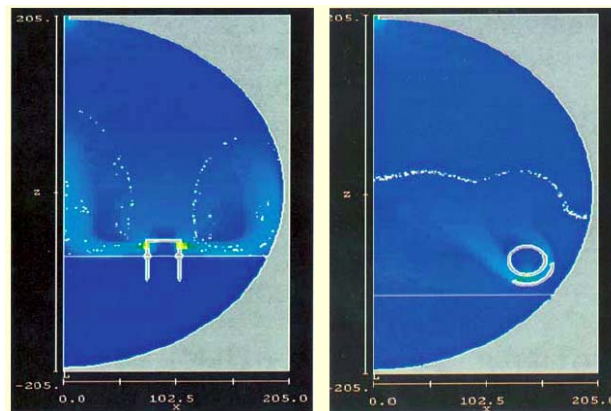
To reduce these parasitic circulations an arrangement of angled deflectors were installed adjacent to each set of orifices. These deflectors served to reduce the oil momentum and to redirect the oil more uniformly in to the bottom of the electrodes.

Installation of these baffles can significantly improve the hydraulic efficiency of the distribution system to nearly 90%. These deflectors, shown schematically in Figure 3, were installed in all five vessels.



**Figure 3: Type Oil/Water Spreader with & without Deflectors**

Through the use of Computational Fluid Dynamics (CFD) and model tests the patented the shrouded inlet spreader was produced.



**Figure 4: CFD Distribution**

Figure 4 shows the CFD study results, the summary on the left shows scattered and turbulent distribution with a box distributor whilst the summary on the right shows minimal turbulence with equal distribution in the vertical plane for the shrouded header.

## ELECTROSTATIC TECHNOLOGY

The most significant improvement was obtained by replacing the Dual Polarity<sup>®</sup> electrostatic transformers on one vessel with a patented electrostatic technology known as Dual Frequency<sup>®</sup>. This aggressive electrostatic technology utilises a proprietary process controller and transformer package to produce an optimised electrostatic voltage field for any crude oil. This technology has demonstrated remarkable performance improvements in pilot facilities and field applications.

The transformer package contains three components that are enclosed in a single oil-filled enclosure. To overcome the load balance problem normally encountered with single phase transformers, it has been designed to operate on a three phase, 480 volts (50 / 60 Hz) power source. The first component conditions the 3 phase 480 volt source using IGBT technology (isolated gate bipolar transistors) and produces a variable amplitude and variable frequency single phase voltage for the primary of the transformer. The second component is the high voltage transformer which steps up the input voltage to a secondary voltage level necessary to promote effective coalescence. The final component is the rectifiers to produce the necessary positive and negative voltages for the electrodes.

A process controller permits the key components of the high voltage waveform to be adjusted by the operators to achieve the most efficient process performance. The microprocessor controller developed to control the output of the variable voltage / frequency transformer is capable of producing a nearly infinite variety of waveform configurations. Four variables define the shape of the waveform including the frequency of the voltage, the maximum and minimum voltages applied to the transformer and the cyclic pattern and rate used to drive the transformer.

**Minimum Voltage** (Threshold Voltage) – used to maximise the water droplet diameter.

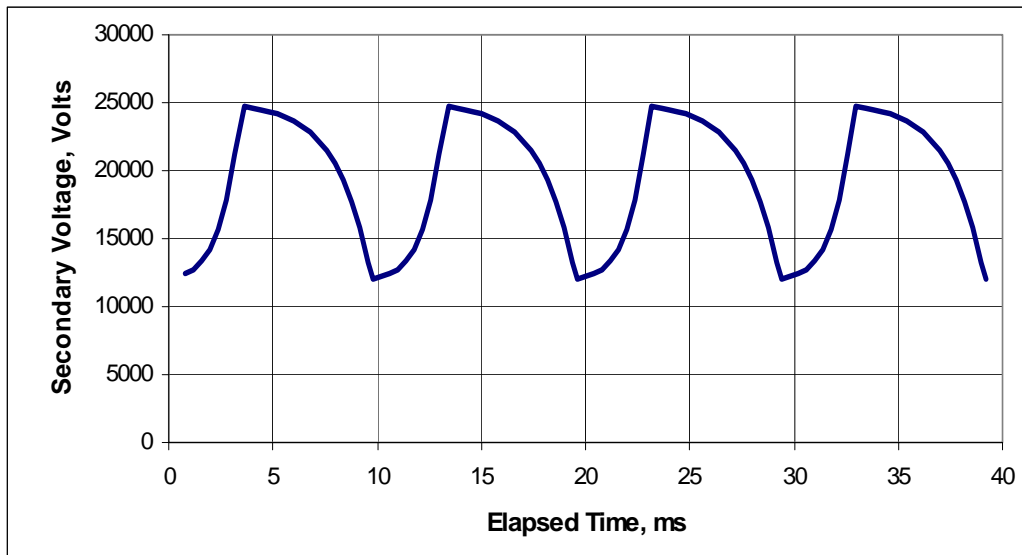
**Maximum Voltage** (<Critical Voltage) – used to energise the smallest water droplets.

**Frequency** – prevents the voltage applied to the positive and negative electrodes from decaying, thus maximising the electrostatic energy applied to the dispersed water to promote rapid droplet growth and maximise the water droplet size.

**Waveform** – may be any conceivable cyclic wave that can be represented mathematically. The controller has been configured with the following waveforms: logarithmic, exponential, sinusoidal, saw tooth, trapezoidal, circular and inverse circular. The exponential waveform is represented in Figure 5. Additionally, the controller permits these waveforms to be skewed to alter the ratio for ramp up and ramp down times.

The relationship of these waveform parameters to the process requirements is understood. For example, where highly conductive crude oils are processed (> 80 nS/m), the primary frequency can be increased to increase the energy delivered to the oil dehydration process. Utilising a medium frequency transformer overcomes the voltage decay associated with conventional 50/60 Hz transformers. In wet crude oils the effective impedance may be very low, resulting in rapid voltage decay from the process electrodes. This decay reduces the effectiveness of the dehydration process by allowing the voltage to fall below the threshold

level required for effective dehydration. Operating with an increased frequency reduces this voltage decay and effectively sustains the applied voltage above the required threshold.



**Figure 5: Typical Exponential Voltage Waveform**

Also, chemicals, temperature, salts, and applied voltages combine to reduce the interfacial tension between the dispersed water droplets and the crude oil. This low interfacial tension (<10 dynes/cm) reduces the natural frequency of the entrained water droplets. By reducing the waveform frequency improved droplet coalescence can be achieved compared to the application of 50/60 Hz power. Operating with the frequency of the waveform below the natural frequency of the entrained droplets prevents the destruction of the large water droplets required for effective dehydration.

Finally, the shape of the voltage waveform can be selected to achieve the best dehydration results. The waveform includes the minimum and maximum voltage levels which are set to increase the percentage of the entrained water that is affected by the electrostatic voltage. Maximum voltages reach the smallest water droplets with sufficient energy to develop a surface charge and promote coalescence<sup>3</sup>. Reducing the voltage to a minimum level will maximise the droplet growth to promote a rapid sedimentation rate.

Figure 5 depicts a typical envelope of the positive secondary voltage using an exponential waveform. The waveform is skewed slightly to ramp up to the maximum voltage slightly faster than it ramps down to the minimum voltage. By shifting (skewing) the voltage cycle to alter the percentage of the waveform used to increase/decrease the voltage it is possible to enhance the droplet growth further. Optimising the waveform details can avoid droplet break-up and enhance droplet coalescence.

Figure 6 schematically shows the component arrangement for the microprocessor controller, the power electronics, the medium frequency transformer and the rectifiers (diodes). The power electronics, transformer, and rectifiers have been packaged in an oil-filled container to overcome distance problems between the electronics and the transformer, to provide cooling

by the recirculation of dielectric oil, and to make the retrofitting of existing AC/DC transformers more convenient.

This Dual Frequency<sup>®</sup> transformer is capable of delivering full current over its entire voltage range, unlike conventional 100% reactance power supplies.

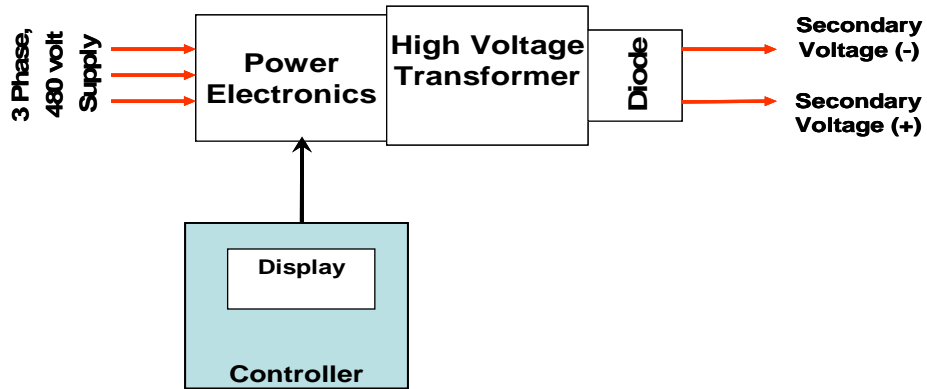


Figure 6: Electrostatic Transformer/Controller Block Diagram

## LABORATORY RESULTS

This unique transformer / controller technology has been extensively tested in a lab pilot. These tests provide ample evidence that the variable voltage / frequency technology can be optimised to permit excellent oil dehydration at significantly higher oil flow rates in a given vessel size.

Results are compared to NATCO Dual Polarity<sup>®</sup> dehydration technology in Tables 1 and 2 shown below.

Constant Oil Flux			
Oil Gravity °API	BS&W @ Flux (BOPD/ft <sup>2</sup> )		Comments
	AC/DC	Dual Frequency	
20.8	0.9% @ 150	0.55% @ 150	North Sea at 50% over original design
30	0.7% @ 175	0.22% @ 175	Okemah, Oklahoma
34	1.2% @ 100	0.80% @ 100	Gulf of Mexico
40	0.1% @ 225	Trace % @ 225	Bristol, Oklahoma

Table 1: Laboratory Pilot Data

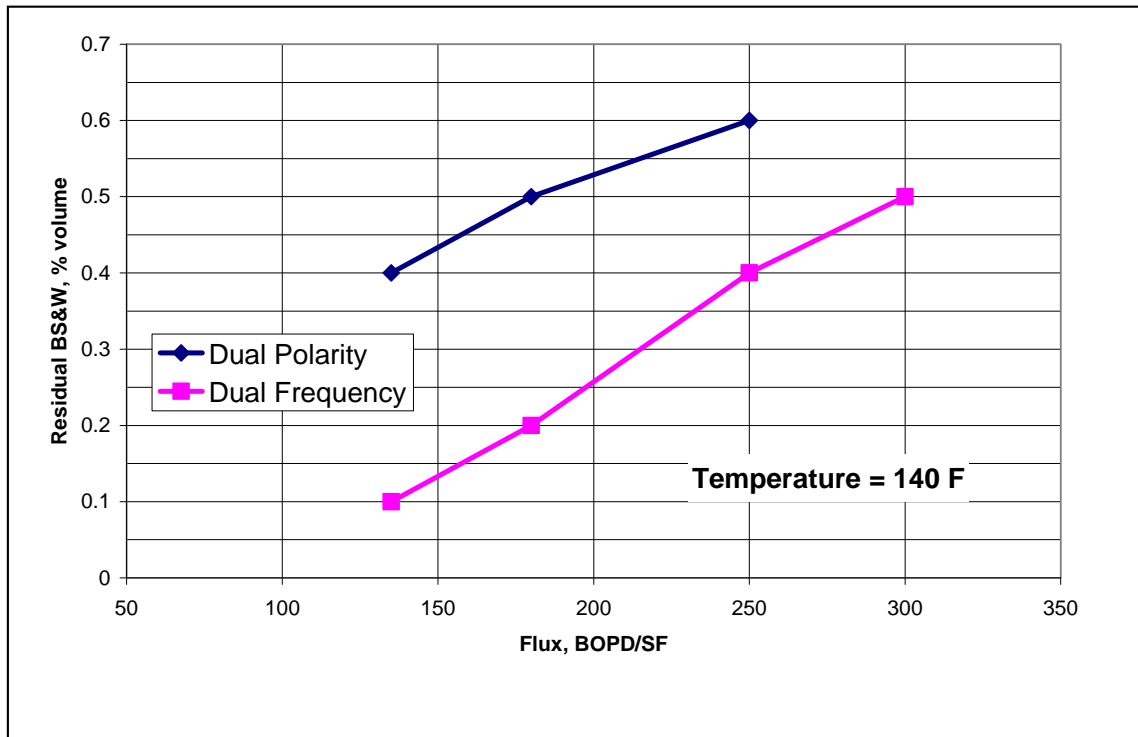
Table 1 compares the BS&W results when both technologies were applied at a constant oil flux.

Increased Oil Flux			
Oil Gravity °API	Flux (BOPD/ft <sup>2</sup> ) @ BS&W		Comments
	AC/DC	Dual Frequency	
16.0	100 @ 0.63%	125 @ 0.56%	Diluted SAGD, Canada
20.2	90 @ 0.38%	220 @ 0.4%	West Sak, Alaska
20.7	90 @ 0.35%	175 @ 0.4%	Bohai, China
24.0	125 @ 0.4%	208 @ 0.4%	Venezuela

**Table 2: Laboratory Pilot Data**

Table 2 compares results obtained when the flux was increased for the Dual Frequency<sup>®</sup> technology to achieve similar BS&W levels.

Pilot tests were also conducted on the 27.1° API crude oil from the customer site utilising both Dual Polarity<sup>®</sup> and Dual Frequency<sup>®</sup> technology prior to equipment installation. Tests were conducted over a wide range of fluxes as shown in Figure 7. This pilot data demonstrates the improvement expected from the field trials. Effluent BS&W levels could be decreased by 75% or the flux could be increased by 90%.



**Figure 7: Laboratory Pilot Results**

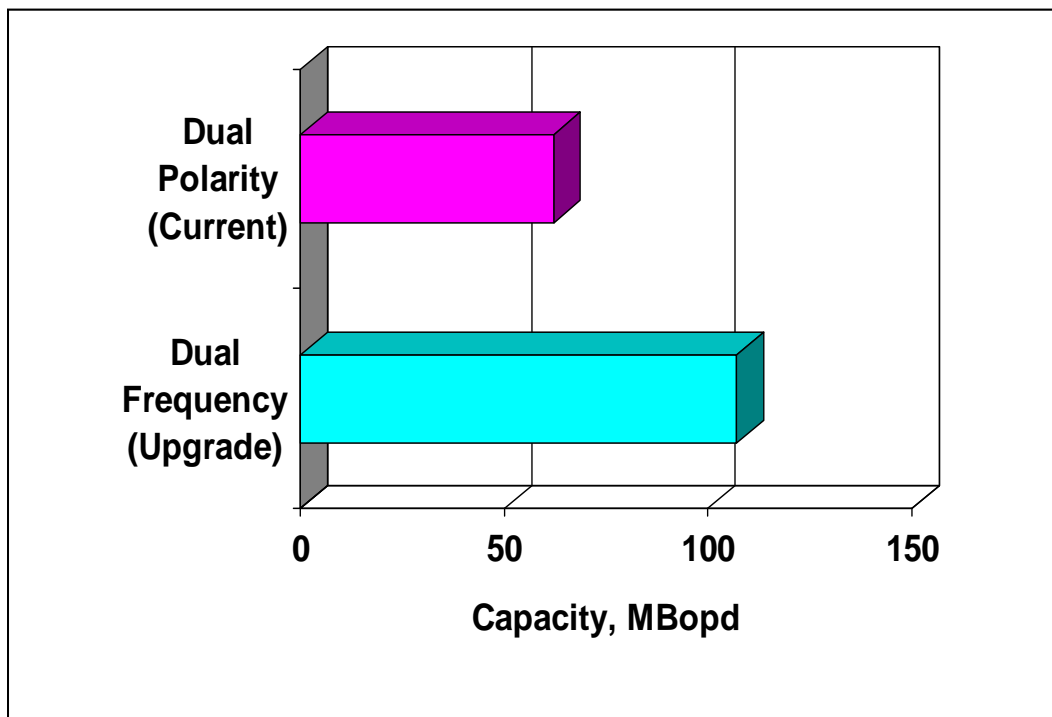
## FIELD TEST

The field trials involved documentation of the initial operating conditions, i.e. voltage configuration, chemical utilisation and effluent BS&W. Data was gathered periodically over a 21-28 day period to establish the baseline performance. The testing program was designed to establish the most aggressive flow rate capable of achieving a 1% BS&W specification. After the baseline data was collected, the Dual Frequency<sup>®</sup> transformer was retrofitted to the process vessel. Voltage, frequency and waveform parameters optimised during lab tests were applied to the transformer controller. A second series of testing was conducted to document the effluent BS&W at the maximum process flow rate.

## FIELD TEST RESULTS

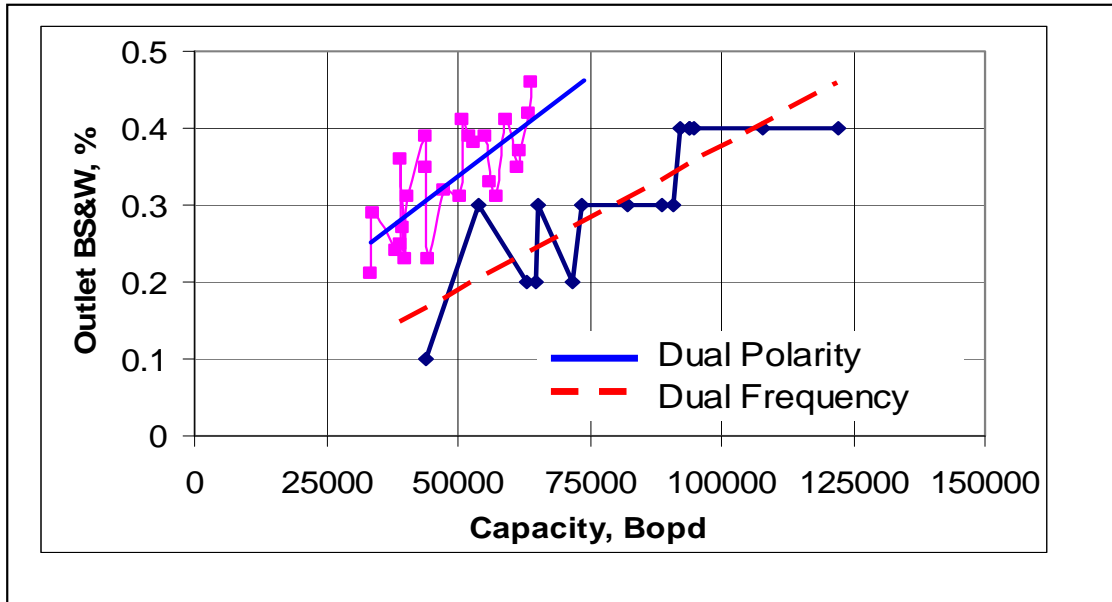
The process performance after installation of the Dual Frequency<sup>®</sup> power supply achieved the following results:

**Capacity** – In the field vessel, the maximum oil flow was hydraulically limited by the external piping manifold and outlet nozzle diameter and not the electrostatic treating capacity of the vessel. However, a significant increase in capacity was demonstrated as shown in Figure 8.



**Figure 8: Maximum Capacity at 0.5% BS&W**

**Dehydration Performance** – The dehydration performance of the Treater was also significantly better after its conversion to Dual Frequency<sup>®</sup> technology. Dehydration performance as a function of vessel throughput is shown in Figure 9. For a comparison with the lab data, a flux of 271 bopd/sq ft is equivalent to 122,000 bopd. Lab results achieved 0.45% BS&W and the field results achieved 0.4%.



**Figure 9: Dual Frequency Performance**

**Potential Improvements** – Two possible improvements were not demonstrated due to the configuration of the field test site. Because heat and chemical injection occurred prior to the common manifold, variation in temperature and chemical treatment in the test vessel was precluded due to the potential for process upset in the other treaters. However, expectations for these parameters are as follows:

**Chemical Effectiveness** – Electrostatic processes function on the water droplet surface the same as the demulsifying chemicals. Up to 50% demulsifier reductions have been realised by other Dual Frequency® installations.

**Temperature Dependence** – The Dual Frequency® power supply promotes a significant growth of the water droplet diameter. These droplets will settle rapidly at the operating temperature. Operation at reduced temperatures should be possible.

## FIELD OPERATING EXPERIENCE

Following the initial testing of the Dual Frequency® electrostatic system at the South American facility the system has been installed at several facilities on and offshore accruing many years of successful operation.

A unit using the Dual Frequency® power system in Wyoming, now in its third year of operation, was installed along side an existing dehydrator using combined AC/DC electrostatic. Both units were the same size and treated the same 16 °API crude oil, at the same temperature. However, the unit fitted with the Dual Frequency® power system could treat 100% more crude oil than the AC/DC unit with both units reducing inlet 11 % BS&W to 0.3 % BS&W.

At a production facility in North Slope Alaska, USA 48,000 bopd of a heavy to medium gravity crude oil with about 5% solids was processed by a 10 ft. diameter x 55 ft. long electrostatic dehydrators using combined AC/DC electrostatic technology. The outlet BSW

dropped to 0.2% from 1% while the vessel capacity was increased from 40000 bopd to 48000 bopd.

At another facility in Gulf of Mexico, an AC/DC Treater which processed 48000 bopd of medium gravity crude was retrofitted with Dual Frequency® power system. A 40% reduction of Demulsifier usage while maintaining or exceeding the required oil specification was confirmed. These fields demonstrated conclusively that this Dual Frequency® electrostatic system provides producers and refiners with the ability to dehydrate and/or desalt oils more efficiently and to better process more difficult crudes

## CONCLUSIONS

The installation of a Dual Frequency® power supply achieved the following performance improvements.<sup>4</sup>

**Balanced electrical load** – The power supply operates on a 480 volt, three phase 50/60 Hz supply and maintains a uniform electrical balance between all power phases.

**Increased power available during process upsets** – Conventional dehydration transformers use 100% reactance to provide protection during process upsets. However, they also fail to maintain sufficient voltage required for effective coalescence. The Dual Frequency® power supply is designed to supply the required coalescence voltage at the maximum available current. During process upsets the coalescing voltage is sustained.

**Optimum process performance** – The Dual Frequency® transformer uses a unique design that permits the electrostatic voltage waveform to be customised for any oil. Matching the waveform to the coalescing requirements it is possible to promote maximum droplet coalescence<sup>5</sup>. Four variables define the shape of the voltage waveform:

**Minimum Voltage** (Threshold Voltage) – used to maximise the water droplet diameter.

**Maximum Voltage** (<Critical Voltage) – used to energise the smallest water droplets.

**Frequency** – prevents the voltage applied to the electrodes from decaying, and maximises the electrostatic energy available to promote rapid droplet growth and maximise the water droplet size.

**Waveform** – several cyclic waveforms have been developed to further promote coalescence. The transformer controller has been configured with the following waveforms: logarithmic, exponential, sinusoidal, square, saw tooth, trapezoidal, circular and inverse circular. The exponential waveform is represented in Figure 3. Additionally, the controller permits these waveforms to be skewed to alter the ratio for ramp up and ramp down times.

This patented, electrostatic technology has been developed by NATCO to expand the utility of electrostatic dehydration into opportunity crudes including SAGD production in Canada, diluted bitumen in South America, high TAN crudes and refinery blends. This Dual Frequency<sup>®</sup> technology will extend the application of electrostatic dehydration to more difficult oils.

The functionality of the transformer permits an electrostatic field to be optimised for oil viscosity, flow rate, oil conductivity, interfacial tension, water droplet population and distribution. The significant performance improvement permits a reduction in capacity from conventional electrostatic vessels. The Dual Frequency<sup>®</sup> transformer can also be retrofitted for debottlenecking existing Dual Polarity<sup>®</sup> treaters without vessel entry.

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